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INSTRUCTION MANUAL

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OPS

OPERATIONAL POWER SUPPLY

HYBRID
design group

Model OPS 500

Serial No. . . . . . .

INSTRUCTION MANUAL

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SECTION I -- INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This instruction manual contains information for the operation, installation and maintenance of the Kepco "OPS–HYBRID" series of high voltage Operational Power Supplies.

1-3 GENERAL DESCRIPTION

1-4 Kepco OPS high voltage Operational Power Supplies are "hybrid" type models which utilize vacuum tubes as their series regulator and solid state devices for the amplifier and reference circuits.

1-5 Kepco Operational Power Supplies are suitable for high speed programming of the output voltage or output current and for a wide variety of other signal processing applications such as summing, integrating and impedance transformation. Kepco OPS Models represent a combination of a d-c power supply and a single ended, unipolar operational power amplifier in an inverting configuration. The functional front panel presents the simplified equivalent circuit of the device and offers all necessary input/output connections on ten universal type binding posts. These terminations are also available on a rear barrier strip. All internal nulling and calibration adjustments are recessed from and accessible through openings in the front panel.

1-6 Kepco OPS high-voltage Operational Power Supplies are constructed in a half-rack configuration on a ventilated, plated steel chassis with a wrap-around perforated cover. The front panel is aluminum, painted light gray.

1-7 SPECIFICATIONS, GENERAL

a) INPUT REQUIREMENTS: 105 to 125V AC or 210 – 250V AC (selectable), 50 to 65 Hz, single phase. AC input input source current approximately 0.6A @ 125V AC.

b) AMBIENT OPERATING TEMPERATURE: –20°C to +65°C.

c) AMBIENT STORAGE TEMPERATURE: –40°C to +85°C.

d) ISOLATION: Output is isolated from the chassis. A maximum of 1000 volts (DC or p-p AC) may be connected between either output terminal and ground.

e) PROGRAMMING: May be controlled by external voltage or current signals. The OPS is a three terminal device, producing a negative output for a positive input with reference to the common (positive).

f) MAXIMUM CAPACITIVE LOADING: 0.001 micro-farads. Excess capacitance slows the response time and may cause instability or high frequency oscillations at the output.

g) INPUT OFFSETS: The fixed (initial) part of the input offset voltage (E_{io}) and the input offset current (I_{io}) can be nulled by means of the recessed front panel controls. The variable parts of the input offsets (ΔE_{io}, ΔI_{io}) are specified in Table 1-2. These offset errors (and any input or bias source used) contribute to the output voltage change (ΔE_o). Since the total output voltage error is also dependent on the input and feedback resistors used, ΔE_o is calculated for each application using the error equation:

$$\Delta E_o = \pm\Delta E_i \ (R_f/R_i) \ \pm\Delta E_{io} \ (1 + R_f/R_i) \ \pm\Delta I_{io} R_f,$$

where R_f and R_i are the feedback resistor and the input resistor respectively (Refer also to Section III of this manual).

h) CURRENT LIMITING: OPS switches automatically into current regulation mode (Automatic Cross-over) if the specified output current is exceeded. The current mode performance is separately specified, (Refer to TABLE 1-2).

1-8 SPECIFICATIONS, PERFORMANCE

a) OUTPUT: (See TABLE 1-1)

MODEL	DC OUTPUT RANGE		OUTPUT IMPEDANCE OHMS SOURCE		SLEWING RATE
	VOLTS	MILLIAMPS	DC	INDUCTANCE	VOLTS/μ SEC.
OPS–500	0–500	0–40	1.25	1 mH	>1.0
OPS–1000	0–1000	0–20	5.0	1 mH	>1.0
OPS–2000	0–2000	0–10	20.0	1 mH	>1.0

TABLE 1-1 OUTPUT SPECIFICATIONS

b) INPUT OFFSETS AND CURRENT MODE: (See TABLE 1-2)

PARAMETER	VOLTAGE AMPLIFIER ΔE_{io}	VOLTAGE AMPLIFIER ΔI_{io}	OUTPUT EFFECTS CURRENT MODE (INTERNAL SENSING)	REFERENCES ±6.2V NOMINAL
AC LINE 105–125/210–250V AC	< 0.1 mV	<10 nA	<10 μA	<0.0005%
LOAD: NO LOAD/FULL LOAD	<1.0 mV	<10 nA	<10 μA	———
TIME: 8 HOURS (STABILITY)	<0.1 mV	<100 nA	<0.01% OF I_o max.	<0.005%
TEMPERATURE COEFFICIENT: PER °C	<0.5 mV	<100 nA	<0.01% OF I_o max.	<0.005%

TABLE 1-2 OFFSET, CURRENT MODE AND REFERENCE SPECIFICATIONS

c) RIPPLE:
   1) Voltage Mode: <0.01% of max. output, or 3 mV (rms), whichever is greater.
   2) Current Mode: < 50 μA (rms).

d) OPEN LOOP DC GAIN: $> 0.5 \times 10^6$ volts per volt.

e) OUTPUT SLEWING RATE: Refer to TABLE 1-1. Slewing rate is measured as the chord to the first time constant on the exponential response to a square-wave program.

f) SINUSOIDAL FREQUENCY RESPONSE: Refer to FIG. 1-3 or calculate by means of the equation:

$$f_{max.} = \frac{\text{SLEWING RATE}}{\pi\ E_{pp}}$$

where E_{pp} is the peak to peak magnitude of the programmed output voltage.

g) TRANSIENT RESPONSE:
   1) VOLTAGE MODE (For step load current): Recovery is an exponential with a 50 microsecond time constant.
   2) CURRENT MODE (For step load voltage): Recovery is the reciprocal of the slewing rate.

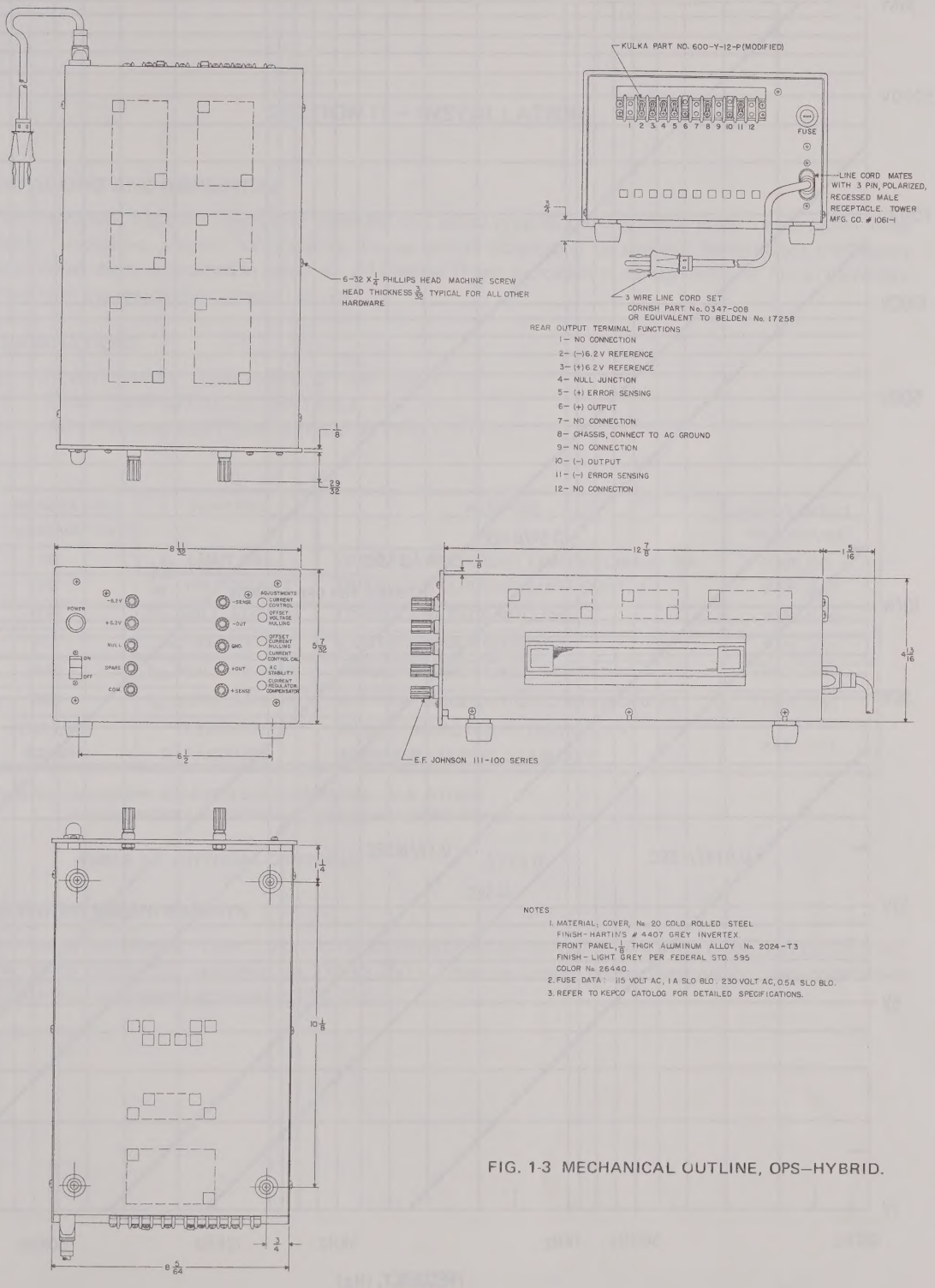
-9 SPECIFICATIONS, PHYSICAL

a) Refer to "Mechanical Outline Drawing" (FIG. 1-3).

-10 ACCESSORIES

a) Rack adapter for single unit: Kepco Model RA–24 with filler panel, Kepco Model RFP 24–2.

b) Rack adapter for two units: Kepco Model RA–24 without filler panel.



NOTES:

1. MATERIAL, COVER, No. 20 COLD ROLLED STEEL
   FINISH - HARTIN'S # 4407 GREY INVERTEX
   FRONT PANEL, 1/8 THICK ALUMINUM ALLOY No. 2024-T3
   FINISH - LIGHT GREY PER FEDERAL STD. 595
   COLOR No. 26440.
2. FUSE DATA: 115 VOLT AC, 1 A SLO BLO. 230 VOLT AC, 0.5A SLO BLO.
3. REFER TO KEPCO CATOLOG FOR DETAILED SPECIFICATIONS.

FIG. 1-3 MECHANICAL OUTLINE, OPS-HYBRID.

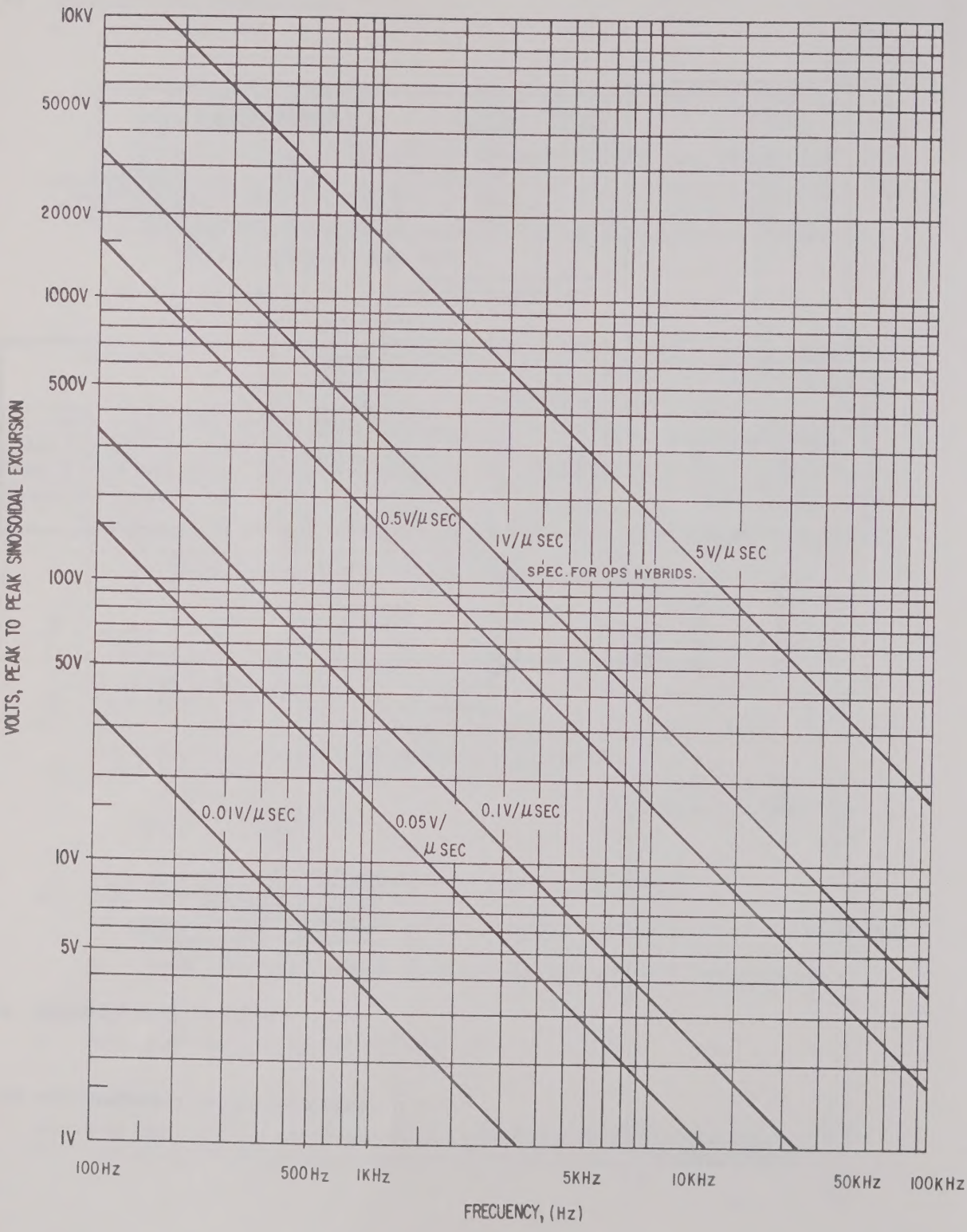


FIG. 1-4 SINUSOIDAL FREQUENCY RESPONSE VS. MAXIMUM P-P OUTPUT AMPLITUDE FOR OPERATIONAL POWER SUPPLIES WITH VARIOUS SLEWING SPEEDS.

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary operational check as outlined in paragraph 2-11 below. If any indication of damage is found, file an immediate claim with the responsible transport service.

2-3 TERMINATIONS

a) FRONT PANEL: Refer to FIG. 2-1 and TABLE 2-2.
b) REAR: Refer to FIG. 2-2 and TABLE 2-3.
c) INTERNAL ADJUSTMENTS (Refer to TABLE 2-1)

REFERENCE DESIGNATION	CONTROL	PURPOSE	ADJUSTMENT PROCEDURE
R6	I_o LIMIT CAL.	OVERLOAD CURRENT LIMIT CALIBRATION	PAR. 5-5
R8	I_o LIMIT ADJUST	OVERLOAD CURRENT LIMIT CONT. ADJ.	PAR. 3-34
R14	E_{io} NULL ADJUST	OFFSET VOLTAGE NULLING	PAR. 3-20
R17	AC STABILITY	LAG NETWORK ADJUSTMENT	PAR. 3-31
R18	I_{io} NULL ADJUST	OFFSET CURRENT ADJUSTMENT	PAR. 3-21
R28	I_o COMP. ADJUST	CURRENT REGULATION COMPENSATION	PAR. 3-42
*C401,402 403,404	FEEDBACK CAPACITORS	TO BE CONNECTED ALTERNATELY ACROSS R_f FOR AC STABILITY	PAR. 3-31

*NOTE: ACCESSIBLE AFTER CASE REMOVAL, ALL OTHER ADJUSTMENTS ACCESSIBLE THROUGH FRONT PANEL.

TABLE 2-1 INTERNAL CONTROLS

2-4 AC POWER REQUIREMENTS

2-5 The Kepco Operational Power Supply is normally delivered for operation on a single phase, 105 to 125 V AC line, 50 to 65 Hz. For operation on 210 to 250 V lines the jumper connections on the main transformer (T201) must be changed as shown in FIG. 2-3.

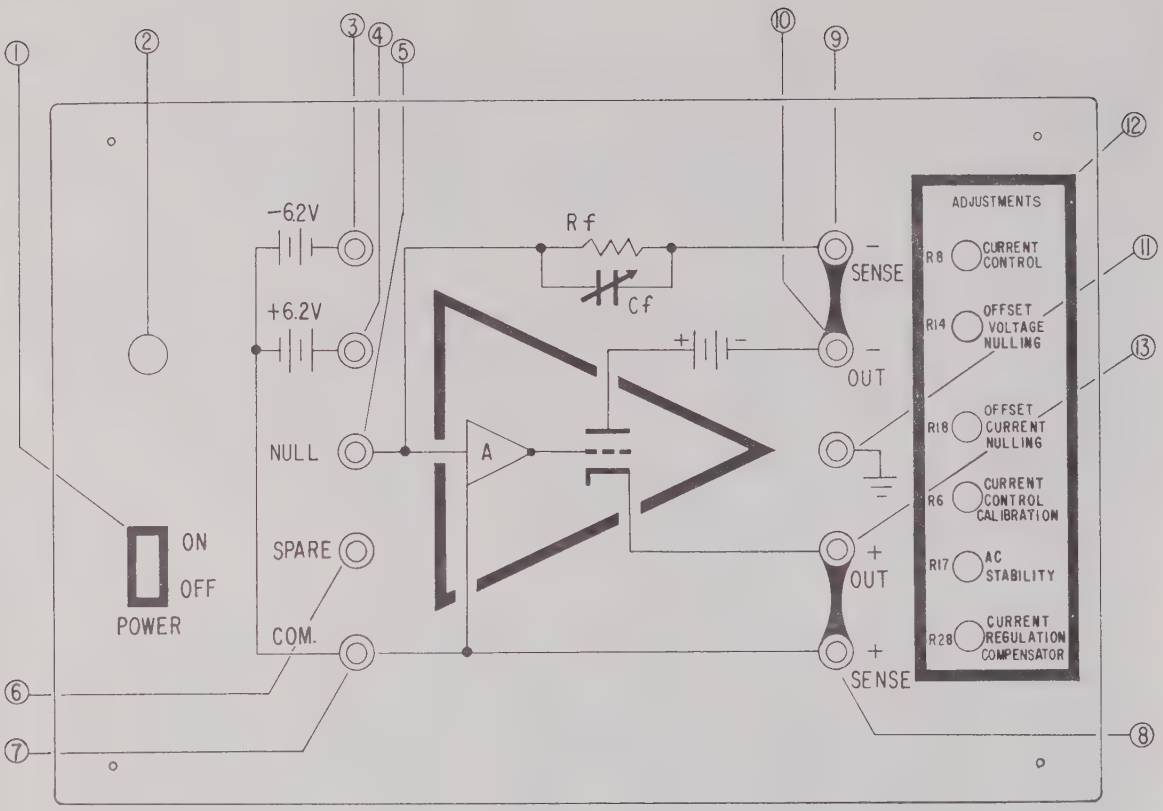


FIG. 2-1 CONTROLS AND TERMINATIONS, FRONT.

NO.	CONTROL OR TERMINATION	FUNCTION
1	AC POWER SWITCH	TURNS POWER "ON" OR "OFF"
2	AC LINE INDICATOR	INDICATES LINE POWER "ON" WHEN ENERGIZED
3	MINUS REFERENCE SOURCE	PROVIDES(–) 6.2V WITH RESPECT TO COMMON
4	PLUS REFERENCE SOURCE	PROVIDES (+) 6.2V WITH RESPECT TO COMMON
5	NULL JUNCTION	INPUT TO AMPLIFIER
6	SPARE TERMINAL	MECHANICAL SUPPORT FOR INPUT COMPONENTS
7	COMMON	COMMON WITH (+) SENSE TERMINAL AND INPUT TO AMPLIFIER
8	(+) SENSE	NORMALLY CONNECTED TO (+) OUTPUT, (REMOVEABLE) FIXED CONNECTION TO COMMON
9	(–) SENSE	NORMALLY CONNECTED TO (–) OUTPUT, (REMOVEABLE)
10	(–) OUTPUT	LOAD CONNECTION
11	GROUND	CHASSIS CONNECTION, RETURN TO AC GROUND
12	ADJUSTMENTS	RECESSED SCREWDRIVER ADJUSTMENTS (See Table 2-1)
13	(+) OUTPUT	LOAD CONNECTION

TABLE 2-2 CONTROLS AND TERMINATIONS, FRONT

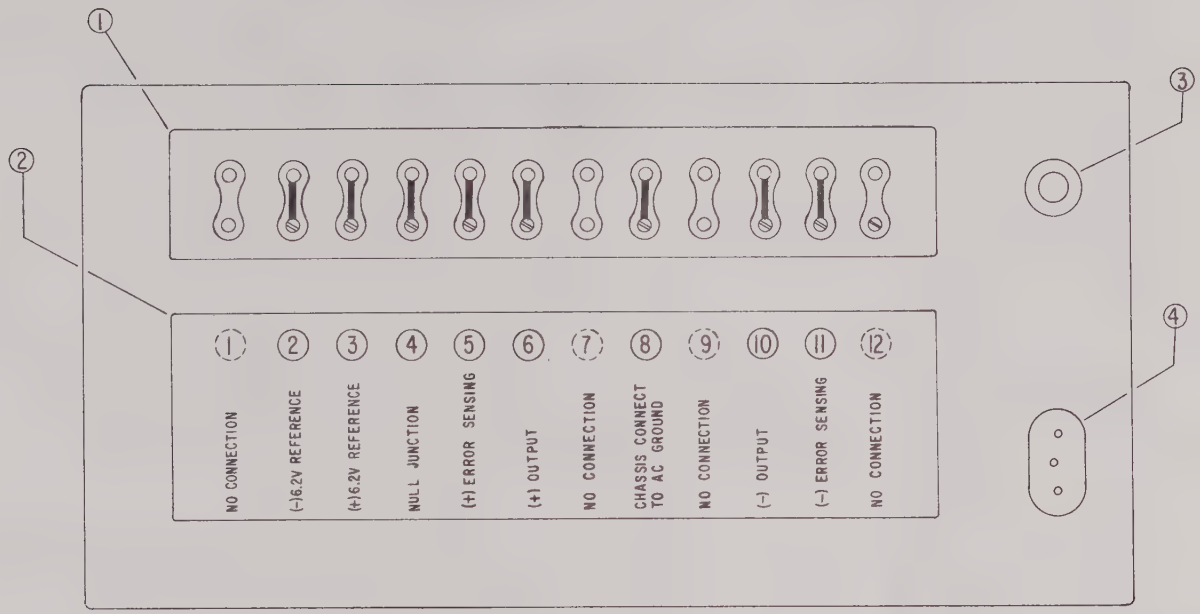


FIG. 2-2 TERMINATIONS, REAR

NO.	TERMINATION	FUNCTION
1	REAR BARRIER-STRIP	EXACT DUPLICATE OF FRONT PANEL TERMINAL FUNCTIONS
2	DECAL	TERMINAL DETAILS FOR REAR BARRIER-STRIP
3	FUSE	PROTECTS PRIMARY OF MAIN TRANSFORMER
4	LINE INPUT	SOCKET FOR (SUPPLIED) SAFETY LINE CORD

TABLE 2-3 TERMINATIONS, REAR

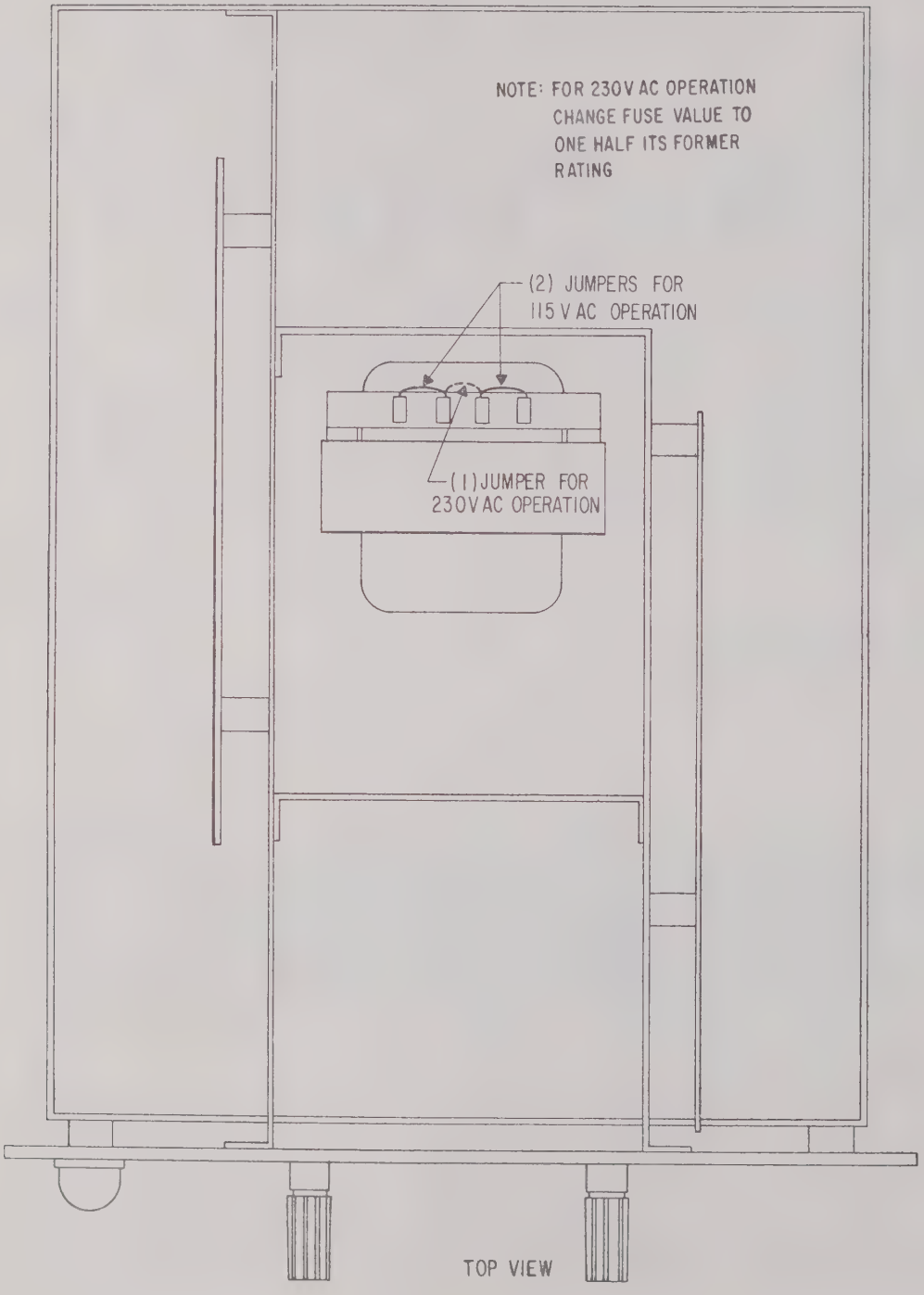


FIG. 2-3 TRANSFORMER CONNECTIONS FOR 115V AC AND 230V AC OPERATION.

2-6 GROUNDING

WARNING

2-7 THE HIGH VOLTAGES PRESENT IN THIS EQUIPMENT MAKE IT IMPERATIVE THAT THE CASE IS KEPT AT GROUND POTENTIAL AT ALL TIMES. If the three-wire line cord with three-prong safety plug (supplied with this equipment) is used in combination with a properly grounded outlet, this is taken care of automatically. If an adapter for a non-grounded outlet is used however, the case must be grounded separately.

2-8 It is good practice to ground one side of the output at all times. Where circuit requirements do not permit grounding of the output, additional precautions against dangerous electrical shocks must be taken. Equipment used in conjunction with high voltage operational power supplies must be able to withstand the operating voltage of the latter. Properly insulated wires are essential.

2-9 COOLING

2-10 The Kepco Operational Power Supply is designed for adequate convection cooling through the wrap-around, perforated case under specified operating conditions. Sufficient space around the unit must be allowed for free air circulation. If the instrument must be mounted into confined spaces, forced air cooling may be necessary to keep the surrounding air within the specified ambient temperature limits.

2-11 OPERATIONAL CHECK

2-12 After unpacking the instrument and before permanent installation, an operational check should be performed as described below:

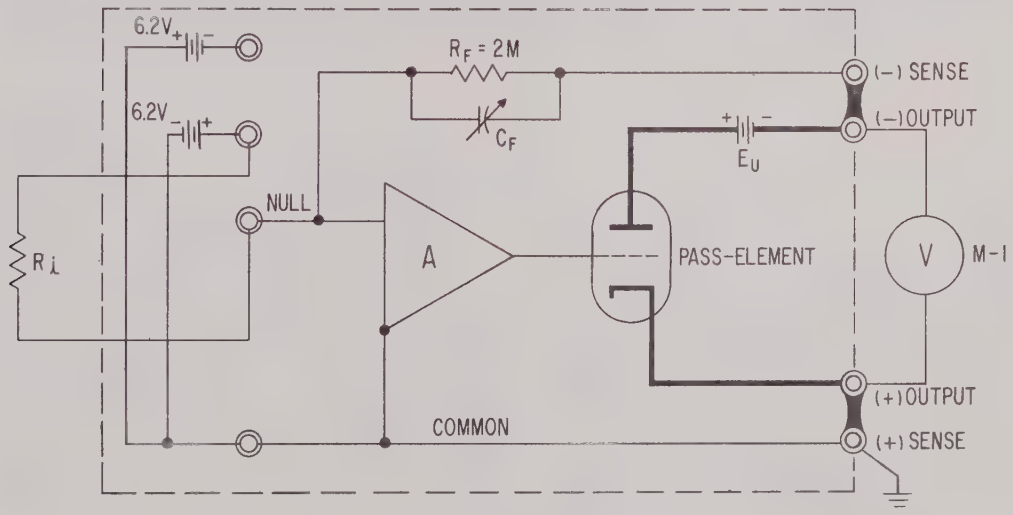


FIG. 2-4 CONNECTIONS FOR OPERATIONAL CHECK

a) The OPS is operated as an operational power supply using the internal reference source and a suitable input resistor R_i. Selection of R_i may procede according to the operational equation:

$$-E_o = E_r \frac{R_f}{R_i}$$

Since E_r = 6.2 V, and R_f = 2 M ohm are given,* we may select the test voltage on the basis of the meter (M1) available. Assuming E_o = 1000 V, we can calculate the input resistor required by

$$R_i = \frac{6.2\ V\ (2 \times 10^6\ \Omega)}{1000\ V} = 12.4 \times 10^3 \text{ ohms.}$$

*See note on page 2-6.

b) A 12.4 K ohm resistor will therefore produce approximately 1000 volts at the output. Connect components as shown and turn unit "on". Observe output voltage at M1. This concludes the preliminary test.

*The built-in feedback resistor (R_f), and the internal reference source (E_r = 6.2 V nominal) are used for this test. The following feedback resistors are used in the OPS Hybrid Models:

OPS–2000 – R_f = 2 M ohm

OPS–1000 – R_f = 1 M ohm

OPS– 500 - R_f = 500 K ohm

(Above example is given for the OPS–2000).

SECTION III – OPERATION

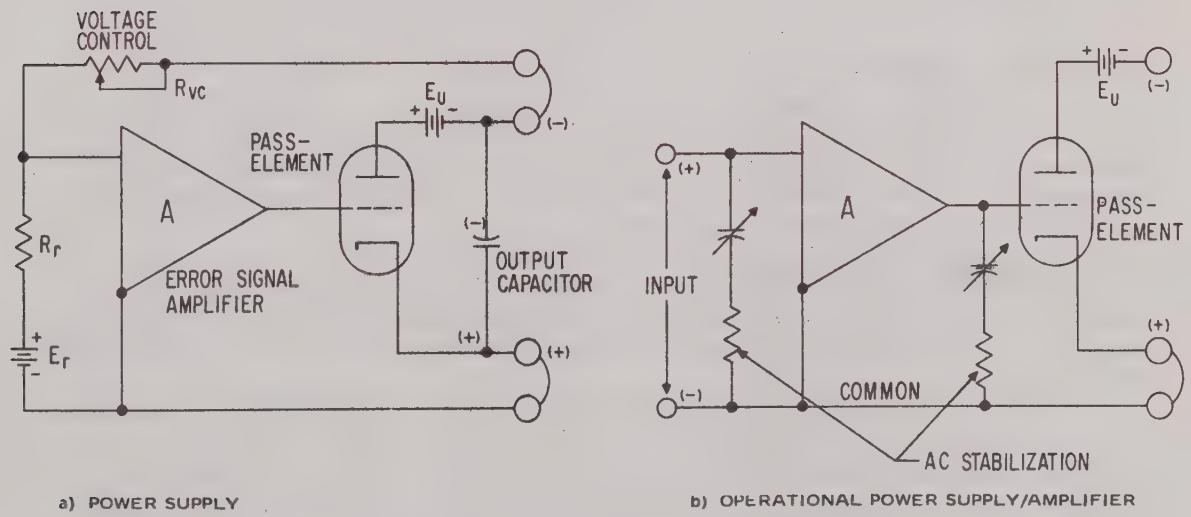
3-1 GENERAL

3-2 This section contains operating instructions for the Kepco Operational Power Supplies preceded by a short review of the principles of operational theory with special reference to the OPS Hybrid Models. The scope of this manual does not allow for through theoretical treatment and only a few of the many possible operational circuits can be discussed. For a more extensive treatment of operational programming the user is refered to the "Kepco Power Supply Handbook", available from your Kepco Representative or directly from: Kepco Inc., Flushing, New York 11352.

3-3 OPERATIONAL POWER SUPPLIES

3-4 For many years, "Operational Amplifiers" have been used in the field of analog computing to perform various mathematical "operations". An operational amplifier is a high gain, DC coupled amplifier, stabilized externally by negative feedback to exhibit gain characteristics depending only on the external feedback components.

3-5 Since a regulated power supply contains such an amplifier in a closed loop configuration and in series with a power amplifier stage (consisting of the driver stage and the series regulator) it can be analyzed in terms of operational terminology. In fact the power supply becomes a high power amplifier if the input terminals are made accessible. To complete the conversion, the bandwidth restricting output capacitor must be removed and the amplifier stabilized. The result is an "Operational Power Supply", programmable like an operational amplifier, with much higher power but single ended output.



a) POWER SUPPLY

b) OPERATIONAL POWER SUPPLY/AMPLIFIER

FIG. 3-1 POWER SUPPLY–AMPLIFIER CONVERSION

3-6 THE IDEAL AMPLIFIER

3-7 For the purpose of analysis, an ideal model of the operational amplifier is proposed and the following assumptions are usually made:

1) The input terminal (null junction) will not conduct current to or from the amplifier.
2) The open loop gain is very large ($A \to \infty$)
3) The input voltage (ϵ) approaches zero when the feedback loop is closed. ($\epsilon \to 0$).

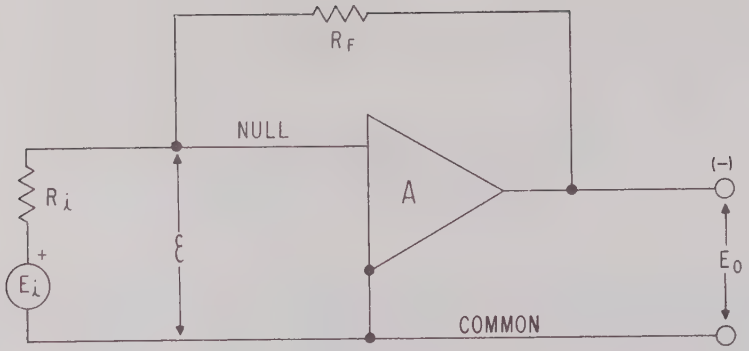


FIG. 3-2 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION)

3-8 Refer to FIG. 3-2. Since (by the previous assumptions) the currents in R_f and R_i are equal, the loop equation may be written as:

$$\frac{E_i - \epsilon}{R_i} + \frac{E_o + \epsilon}{R_f} = 0 \quad \text{(Eq. 1)}$$

By definition, $E_o = -A\epsilon$ where A represents the open loop gain. Also $\epsilon = \frac{E_o}{A}$

If we let $A \to \infty$, $\epsilon \to 0$ then (Eq. 1) becomes: $\frac{E_i}{R_i} + \frac{E_o}{R_f} = 0$

or in the more familiar form, $E_o = -E_i \frac{R_f}{R_i}$ (Eq. 2) where $\frac{R_f}{R_i}$ represents the closed loop gain G.

3-9 THE PRACTICAL AMPLIFIER

3-10 The closed loop relationships derived for the ideal model of the operational amplifier may be applied to the practical case with very small predictable errors which in addition can be compensated for. The "ideal" amplifier equation (2) for example may be used to calculate the magnitude of the feedback and input components with negligible errors which will be well within the component tolerances. In evaluating the DC performance however, these errors can not be neglected.

3-11 AMPLIFIER OFFSETS. In developing the ideal amplifier model we tacitly assumed the null junction voltage and current to be zero, causing the "ideal" equation (2) to be valid. In reality however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{io}) and an offset current (I_{io}). The modified version of the amplifier model can be shown with these error sources as in FIG. 3-3.

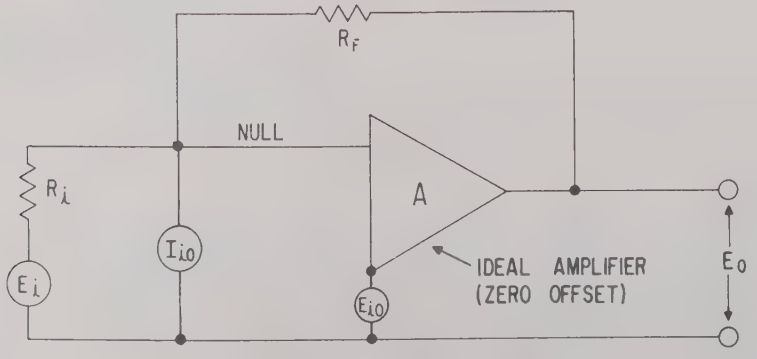


FIG. 3-3 AMPLIFIER WITH INPUT OFFSET SOURCES

3-12 Although the initial values of both offsets may be zeroed by compensating sources of opposite polarities (as in the OPS) their variations with AC input source, output load, temperature and time do appear at the input and are specified as ΔE_{io} and ΔI_{io} in Section I, and repeated here:

SPECIFICATION	CHANGE IN OFFSET VOLTAGE (ΔE_{io})	CHANGE IN OFFSET CURRENT (ΔI_{io})	CHANGE IN REFERENCE VOLTAGE (±) 6.2 V NOMINAL
LINE: (105 to 125V AC)	<0.1 mV	<10 nA	<0.0001%
LOAD: (NO LOAD to FULL LOAD)	< 1 mV	<10 nA	———
TIME: (8 HOURS)	<0.1 mV	<100 nA	<0.005%
TEMPERATURE: PER °C	<0.5 mV	<100 nA	<0.005%

TABLE 3-1 OPS–HYBRID SERIES, DC SPECIFICATIONS

3-13 Considering both offset variations, the modified expression for the output voltage (with the initial or fixed parts of E_{io} and I_{io} nulled) becomes:

$$E_o = E_i \frac{R_f}{R_i} + \Delta E_{io} \frac{R_f}{R_i} + 1 + \Delta I_{io} R_f \quad (3)^*$$

Ideal Part — Output effect, offset voltage change — Output effect, offset current change

As seen from equation (3), the offset voltage variations (ΔE_{io}) are multiplied by unity, plus the gain ratio R_f/R_i to obtain its contribution to the output voltage change, while the offset current variations are multiplied by the value of the feedback resistor (R_f). The separation of the specifications for ΔE_{io} and ΔI_{io} not only allows an analysis of the contributions from each offset variation, but also permits component selection such as to minimize the effects of either offsets or find an acceptable compromise.

3-14 A practical example will illustrate the usefulness of the concept: For an application requiring a gain of 10, an operational programming circuit is to be set up with a Model OPS 2000.
For the table of specifications, the line regulation is found to be:

$\Delta E_{io} = 100\,\mu V$
$\Delta I_{io} = 10$ nA

If we let $R_i = 100$ K ohms, then for $R_f/R_i = 10$, we need $R_f = 1$ megohm. The expected output variation due to AC line changes are (from Eq. 3):

$$\Delta E_o = \Delta E_{io} \frac{R_f}{R_i} + 1 + \Delta I_{io} R_f$$

$$= 100\,\mu V\,(10 + 1) + 10\text{ nA}\,(10^6\text{ ohms})$$

$$= 1.1\text{ mV} + 10\text{ mV}$$

ΔE_o due to ΔE_{io} — ΔE_o due to ΔI_{io}

The contribution of ΔI_{io} are seen to be almost ten times that of ΔE_{io}, due, of course, to the choice of a relatively large feedback resistor. Generally, in low gain applications, it is wise to select lower values for the feedback and input resistors if the loading on the input source will permit it; if for example: $R_i = 10$ K and $R_f = 100$ K (retaining the previous gain ratio of $R_f/R_i = 10$), ΔE_o would only be 1.1 mV + 1 mV = 2.1 mV, calculated similar to the the previous results.

Using the same amplifier in an application with a required operational gain of 100, we select R_i to be 1 K ohm and $R_f = 100$ K thus establishing the desired ratio ($R_f/R_i = 100$). For this choice of input and feedback elements, we find the output line regulation to be.

*NOTE: This equation does not include variations in the input source. The input source error, multiplied by R_f/R_i, must be added as an additional term in equation (3)if one of the built-in reference sources is used.

$$\Delta E_o = 100\,\mu V\ (100+1) + 10nA\ (1 \times 10^5\ ohms)$$
$$= 10.1\ mV + 1\ mV$$
$$\Delta E_o \text{ due to } \Delta E_{io} \qquad \Delta E_o \text{ due to } \Delta I_{io}$$

In this case the contribution from ΔE_{io} is dominant. Its effect can only be reduced by externally limiting wide variations of the AC source voltage. Similar calculations to the above examples may be made to predict the effects of load changes, temperature variations or stability (changes in output voltage with time).

NOTE: The examples as presented here constitute "worst case" conditions. In practice the output change (ΔE_o) is usually much less due to cancellation effects.

3-15 OPERATING THE OPS.

3-16 GENERAL. The OPS is of hybrid design, using a vacuum tube for the pass-element. A warm-up time of approximately 30 seconds is therefore required after turn-on to allow the cathode of the tube to reach proper operating temperature. Before critical measurements are made, a longer warm-up period is required to insure thermal equilibrium of all components.

3-17 EXTERNAL CONNECTIONS. Input and output connections may be made either on the front panel binding posts or at the rear barrier-strip. (Refer to FIG. 3-4) In all following diagrams, only the front panel terminations will be shown.

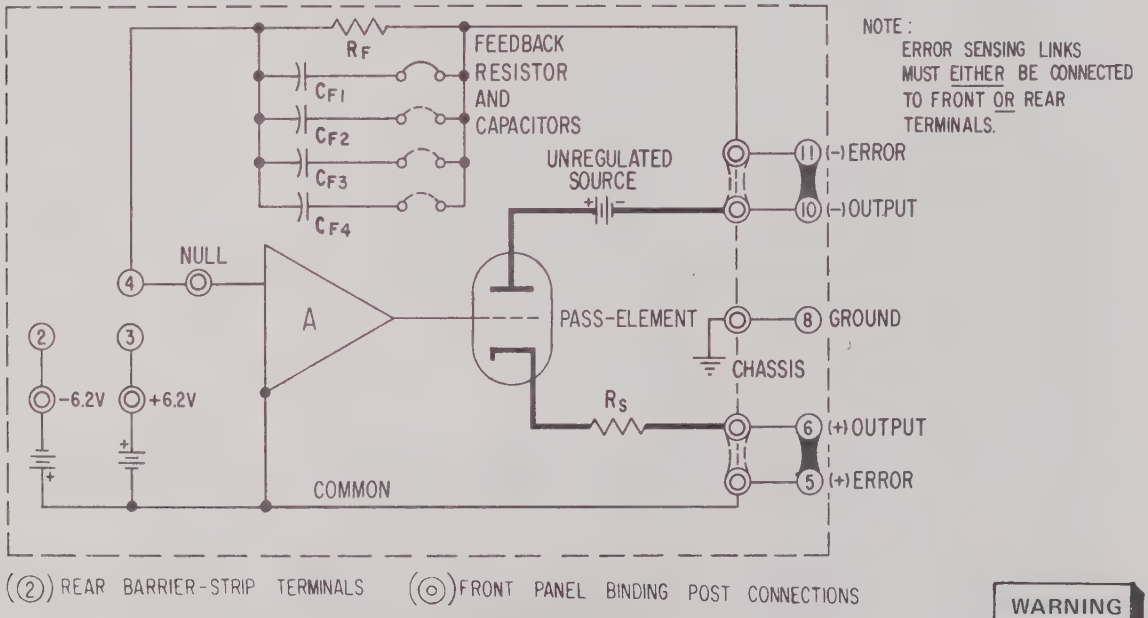


FIG. 3-4 OPS—HYBRID MODELS, REAR BARRIER-STRIP TERMINALS AND FRONT PANEL BINDING POST CONNECTIONS

WARNING

1) THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES. ALL CONNECTIONS TO AND FROM THE UNIT SHOULD BE MADE WITH THE AC LINE POWER COMPLETELY REMOVED.
2) Wires and/or cables must be properly insulated, and terminated to make accidental touch impossible.
3) GROUNDING OF THE CHASSIS ON THIS INSTRUMENT IS IMPERATIVE. Grounding of the positive output terminal is recommended if at all possible. If output is not grounded, external programming sources must be rated for an isolation voltage equal to the maximum output voltage of the OPS.
4) Programming and output connections may be either made at the front binding posts or at the rear barrier-strip terminals. All connections must be tight and secure.
   Diagrams in this section show front binding post connections only. For the corresponding rear terminal numbers see FIG. 3-4.
5) The maximum output voltage of the OPS appears also at the feedback terminals between the null junction and the minus output and error sensing terminals. Consequently, components connected to the feedback terminals (resistors or capacitors) must be rated to with-stand at least the maximum rated output voltage.

3-18 INITIAL ADJUSTMENTS (Refer to FIG. 2-1 for location of controls.)

3-19 GENERAL. Built-in trim rheostats provide for the adjustment of the fixed (initial) part of the amplifier offsets. The procedure outlined below should be part of each operating set-up to insure accuracy and minimize programming errors. USE ONLY INSULATED ADJUSTMENT TOOLS.

3-20 VOLTAGE OFFSET NULLING PROCEDURE

a) Connect external components as shown in FIG. 3-5. The external feedback resistor can be a decade box or a rheostat. Both, resistors and the by-pass capacitor should be of high quality, the resistors must have temperature coefficients of 20 parts per million or better, the capacitor should be a mylar type of polystrene. "M1" should be a sensitive, null detecting instrument such as the Millivac Model MV-07C or equivalent. THE VOLTAGE RATING OF BOTH, RESISTIVE AND CAPACITIVE COMPONENTS, MUST BE GREATER THAN THE MAXIMUM OUTPUT VOLTAGE OF THE OPS.

b) Turn OPS "on" and allow sufficient warm-up time. Locate the offset controls at the front panel (See FIG. 2-1). With switch S1 closed, adjust "VOLTAGE OFFSET NULLING" until the null detector M1 reads exactly zero volts.

c) The adjustment may shift slightly as the OPS (as well as the null detector) are warming up. Repeat as necessary.

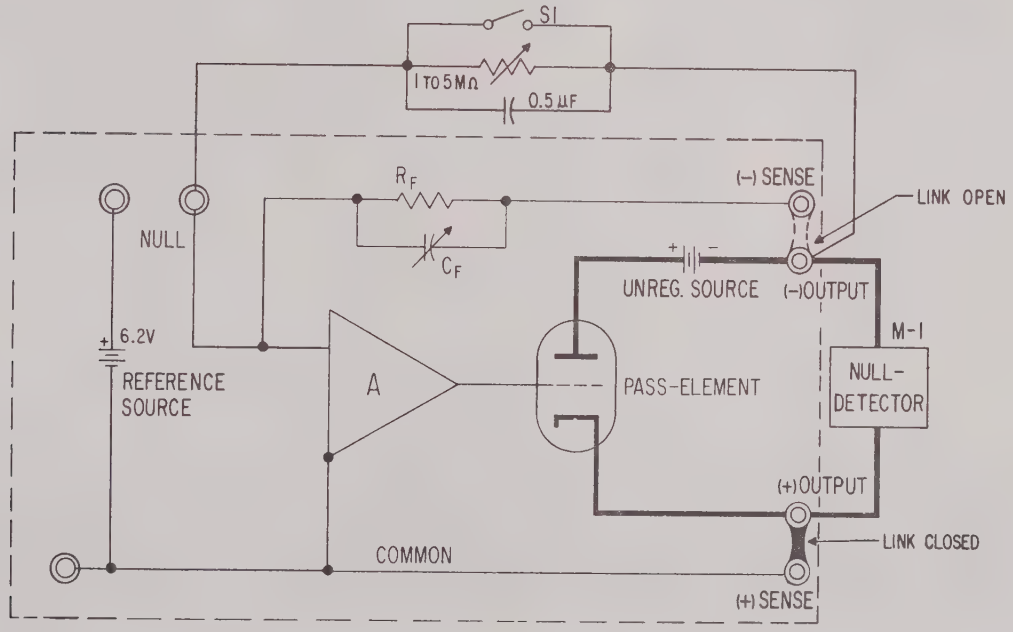


FIG. 3-5 TEST SET–UP FOR OFFSET NULLING

3-21 CURRENT OFFSET NULLING PROCEDURE

a) Retain identical test set-up as shown in FIG. 3-5. Open S1. Locate "OFFSET CURRENT NULLING" control on the front panel (See FIG. 2-1) and set to exact zero volts as read-out on M1. Increase sensitivity of adjustment by increasing the resistance placed across the feedback terminals. Repeat adjustment.

b) The adjustment becomes more critical as the feedback resistance is raised. With care, the offset current can be reduced to a few nano amperes. (1 nano ampere across 5 megohm represents an output voltage of 5 mV as rated out on M1), Offset current nulling results in raising the input impedance looking into the feedback terminals. This becomes important in applications where the OPS is connected as an impedance transformer, since the feedback terminals represent the "input" of the circuit. Impedance in this case will be directly proportional to the residual offset current. With careful adjustment, Z_{in} can be raised to 10^7 to 10^8 ohms.

3-22 SELECTION OF INPUT AND FEEDBACK RESISTORS

3-23 GENERAL. Once the offsets have been properly nulled and the device has reached thermal equilibrium, the necessary operational gain can be determined and the circuit components may be caluclated for the application at hand. Since the applications will vary widely, component selection can be demonstrated on a few examples only. For further circuit information and many other possible applications please consult the Kepco "Power Supply Handbook" and the standard texts on operational amplifier applications.

3-24 Example I: A Model OPS 2000 is to be programmed for a sine wave output of 2000 volts peak to peak, into a resistor load. The input source available is a sine wave generator, delivering a maximum amplitude of 10 volts peak to peak into a 600 ohm impedance.

3-25 Since the OPS 2000 is a unipolar device, the input source must also either by unipolar (vary in one direction only) or, the DC output level of the amplifier must be pre-biased in such a way, that the amplified variations from a bi-polar source will be confined within its output range. (Refer to FIG. 3-6)

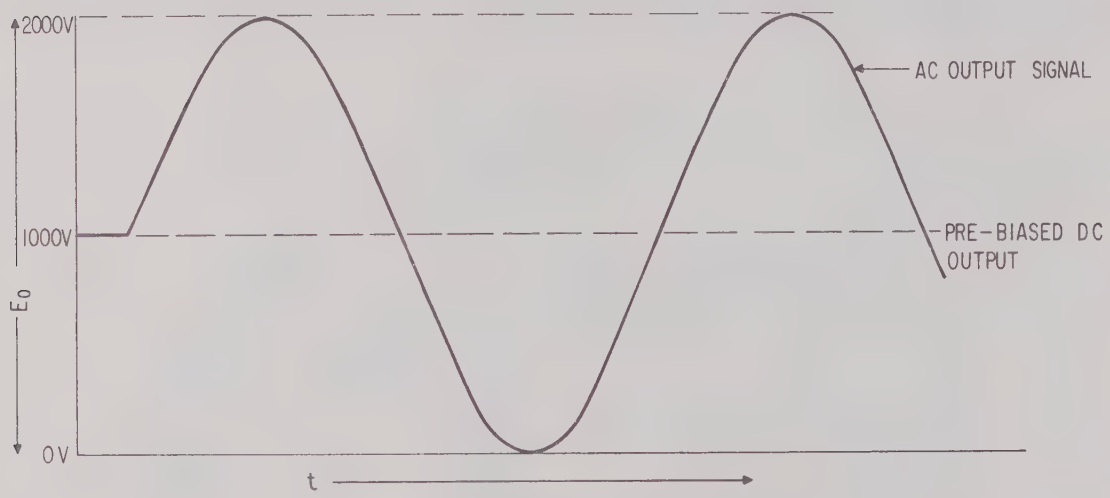


FIG. 3-6 OPS-2000 PRE-BIASED TO ACCOMODATE A BIPOLAR INPUT

In the above example, since we want an AC output swing from zero to 2000 V peak to peak and the input source is bipolar, we must adjust the DC output for 1000 volts (mid-point) so that the amplified AC signal can swing around the 1000 volt axis. The output will also be unipolar, i.e. the 2000 volt p-p wave form will have a 1000 V DC component. (See FIG. 3-6)

3-26 The desired DC level was established to be 1000 V. The input reference source (E_r) can deliver the necessary control current (I_b), which, in conjunction with the built-in feedback resistor (R_f), will establish the desired DC bias at the output of the OPS. Applying the derived operational equation (Eq. 2) to our DC conditions and using 0.5 mA control current, with the built-in feedback resistor (R_f):

$$E_o = -E_i \frac{R_f}{R_r} \qquad \text{(Eq. 2)}$$

Since E_o = 1000 volt,
E_i = 6.2 volt (nominal),
R_f = 2 megohm,

R_r is given by: $R_r = \dfrac{6.2\text{ V (2 megohm)}}{1000\text{ volts}} = \dfrac{12.4 \times 1 \times 10^6}{1 \times 10^3} = 12.4\text{ K ohms.}$

Part of R_r may be made adjustable to adjust I_b to exactly 0.5 mA resulting with the built-in feedback resistor (R_f) in an exact DC output voltage of 1000 V.

3-27 The AC output swing was established to be 2000 volts. The AC conditions are therefore as follows:

E_o = 2000 V (p-p)
E_i = 10 V (p-p)
R_f = 2 megohm

and it remains to calculate R_i the coupling resistor by means of our operational equation. From the above condition,

$$R_i = \frac{10\ V\ (2\ M\Omega)}{2000\ V} = 10\ K\ ohms$$

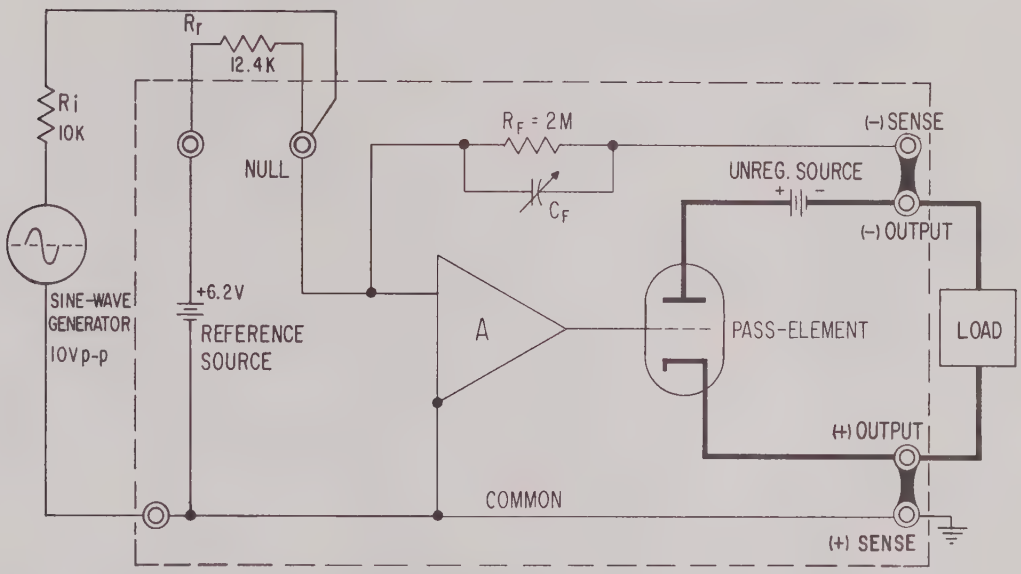


FIG. 3-7 SINE–WAVE PROGRAMMING

It is important for temperature stability and accuracy reasons that the selected components are quality, wire wound resistors with close tolerances. Portions of the selected input and reference resistors may be made variable if extreme accuracy is required. The complete programming set-up is now connected to the instrument as shown in FIG. 3-7 and operation can commence. From the frequency response chart (FIG. 1-4) it is seen that the OPS 2000 with a specified slewing rate of 1 x 10^6 V/sec. has a maximum frequency response of about 160 Hz at maximum output voltage. Beyond 160 Hz, amplitude reduction and slope distortion will take place.

3-28 Example II: An OPS–500 is to be programmed by a positive going triangular wave generator (Kepco Model FG-100 Function Generator) able to develop a control current of 1 mA across 1000 ohms to provide a triangular wave output of 150 volts p-p. (Refer to FIG. 3-8).

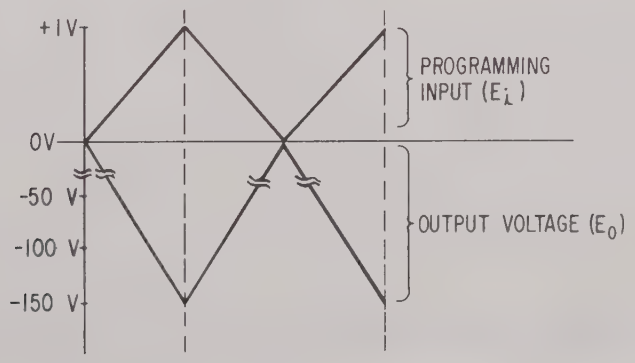


FIG. 3-8 OPS PROGRAMMED WITH POSITIVE GOING INPUT SOURCE

3-29 Since the input source develops a positive 1 volt (E_i) at 1 mA, R_i = 1 K ohm. For 150 volts of output R_f is calulated to be:

$$R_f = \frac{E_o R_i}{E_i} = \frac{150\ V\ (1\ K\Omega)}{1\ V} = 150\ K\ ohm.$$

No DC biasing is necessary in this case since the input source is unipolar. The programming set up is now connected as shown in FIG. 3-9 and programming can commence.

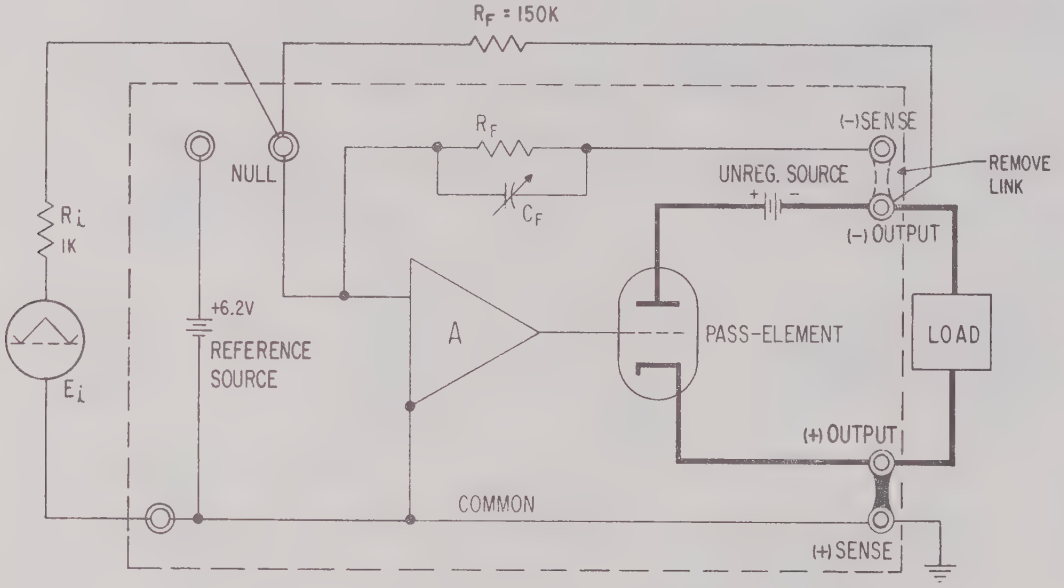


FIG. 3-9 PROGRAMMING WITH A POSITIVE GOING TRIANGULAR WAVE

3-30 Example III: A 500 volt square wave is required. The input source is a square wave generator with a negative output and able to deliver at least 1 mA control current (H.P. Model 211A or eq.). In this case the amplifier must be biased for its maximum DC output voltage. Using an OPS–2000 as an example, and the 2000 volt DC output level as reference, the output is now programmed down to 1500 volts.(Refer to FIG. 3-10.)

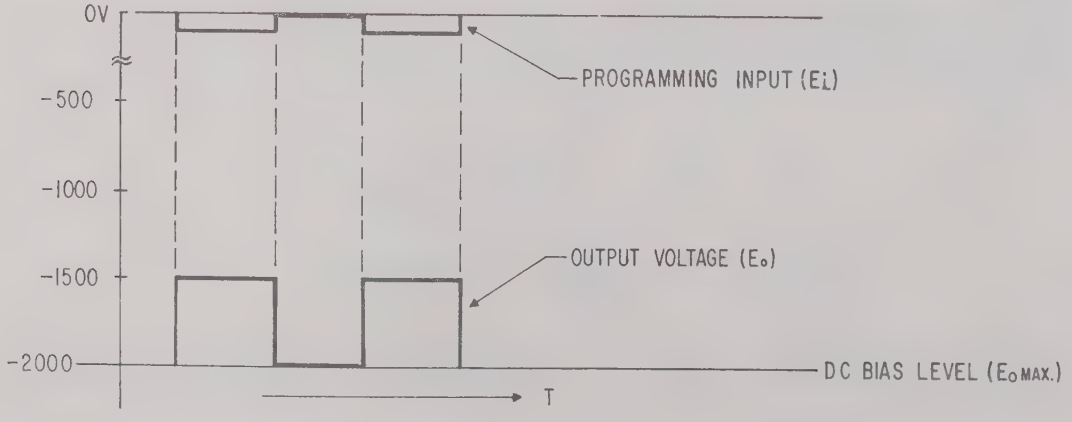


FIG. 3-10 OPS BIASED FOR NEGATIVE INPUT SOURCE

Since either output on the OPS may be grounded, this programming arrangement has been proven very satisfactory in cases where the input polarity can not be changed readily. Component selection takes place in the manner described before: Since the input source amplitude may be adjusted, we let E_i = 25 volts (p-p). E_o is given by our requirements, E_o = 500 volts. The operational gain needed therefore is 20. Letting the control current for convenience, equal 1 mA, R_f must then be 500 K ohms and R_i = 25 K. This will take care of our AC requirements.

For DC biasing, we make use of the internal reference source. From the AC calculations we have established R_f = 500 KΩ and can calculate the needed reference resistor R_r for the Bias needed:

DC E_o = 2000 V
R_f = 500 KΩ
E_r = 6.2 V (nominal)

$$R_r = \frac{E_r R_f}{E_o} = \frac{6.2\text{ V}\ (500\text{ K})}{2000\text{ V}} = 1.55\text{ K}$$

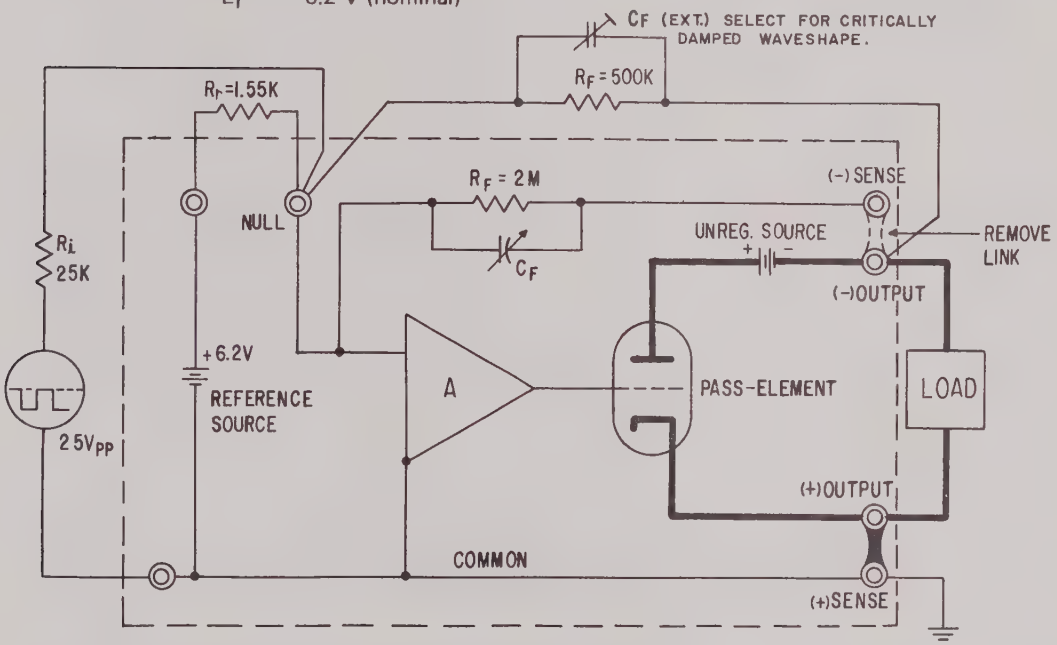


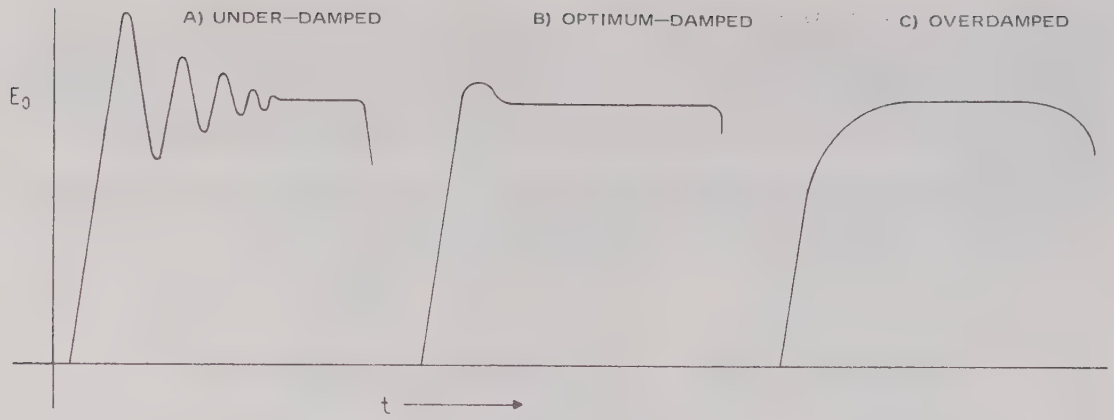
FIG. 3-11 SQUARE–WAVE PROGRAMMING WITH A NEGATIVE SOURCE

Connect the programming set-up as shown in FIG. 3-11 and commence programming. Monitor output waveform across the load with a suitable oscilloscope. Overshoot and other wave form distortions may be corrected by adjustments described in the following paragraph.

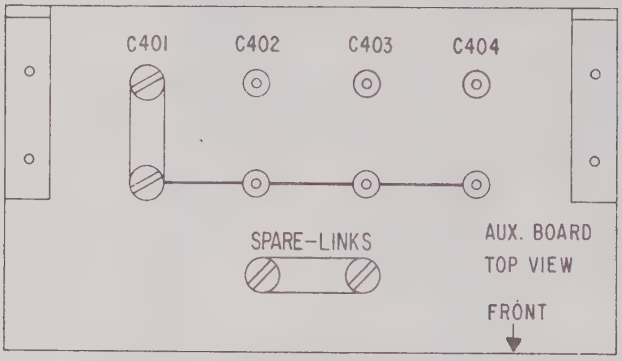
3-31 AC STABILITY ADJUSTMENTS

3-32 The underdamped characteristics of an operational power supply or amplifier may give to "ringing," "overshoot," or oscillation in the output, especially when a square wave is programmed into loads which are not purely resistive. In the OPS, provisions have been made for stabilizing the amplifier for a wide range of load conditions. A feedback capacitor "strapping-arrangement" is provided internally, accessible after cover removal, and an adjustable lag network may be controlled from the front panel. The AC characteristics of the OPS are optimized at the factory by programming a square wave into a resistor load, using a low feedback ratio ($G = R_f/R_i = 1$). The test set-up for lag network adjustments is similar to that shown in FIG. 3-11 with the exception of the feedback resistor, which now is also 25 K ohms. A positive-going square wave is used at the input so that the DC bias arrangement is not needed and the output amplitude will equal the input signal amplitude.

NOTE: When external feedback resistors are used, the link from (−) output to (−) sense is opened, disconnecting the built-in internal feedback resistor ***as well as the internal feedback capacitors.*** Therefore, an ***external*** feedback capacitor must be selected when using external feedback resistance.



A) SQUARE WAVE RESPONSE



B) LOCATION OF FEEDBACK CAPACITORS

REFERENCE DESIGNATION	OPS 500	OPS 1000	OPS 2000
C401	400pF	200pF	100pF
C402	1000pF	500pF	200pF
C403	2000pF	1000pF	500pF
C404	5000pF	2000pF	1000pF

C_f, TABLE OF VALUES

FIG. 3-12 AC RESPONSE ADJUSTMENTS.

3-33 Refer to FIG. 3-12. Turn OPS "on" and observe output wave form on a suitable oscilloscope (Tektronix 545 or eq.). Select feedback capacitor yielding the desired response. Several values may be connected in parallel by means of the provided spare links. Adjust "AC STABILITY" trim-resistor together with the feedback capacitance.

3-34 OVERLOAD PROTECTION

3-35 The Kepco Operational Power Supply is equipped with a continuously adjustable "CURRENT CONTROL". This control sets the short-circuit current in the specified range for each model. When load current approaching the value of the adjusted point is drawn by the load, the OPS limits the output current sharply until the overload is removed. In this manner the OPS is made completely short circuit-proof. (Refer to FIG. 3-13).

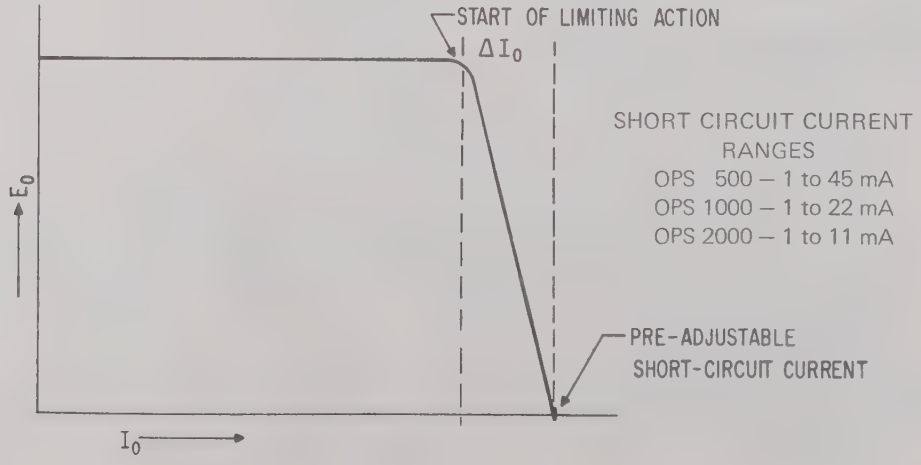

START OF LIMITING ACTION
ΔI_0
SHORT CIRCUIT CURRENT RANGES
OPS 500 — 1 to 45 mA
OPS 1000 — 1 to 22 mA
OPS 2000 — 1 to 11 mA
PRE-ADJUSTABLE SHORT-CIRCUIT CURRENT
E_0
I_0

FIG. 3-13 CURRENT LIMIT CHARACTERISTICS, OPS—HYBRID MODELS.

3-36 ADJUSTMENTS. Three adjustments in the OPS Hybrid Models pertain to the overload circuitry:

a) The "CURRENT CONTROL" adjustment.
b) The "CURRENT CONTROL CAL." adjustment.
c) The "CURRENT REGULATION COMPENSATOR" adjustment.

All controls have been factory adjusted to limit the output current at the specified value and to provide sharpest possible limiting at this current. If other limits as the provided maximum are desired, the controls can be adjusted following the procedure given below. The "CURRENT CONTROL CAL." control should not be adjusted unless components associated with the current limiting circuitry have to be replaced. This control calibrates the "CURRENT CONTROL" so that its maximum clockwise position coincides with the maximum allowable short circuit current.

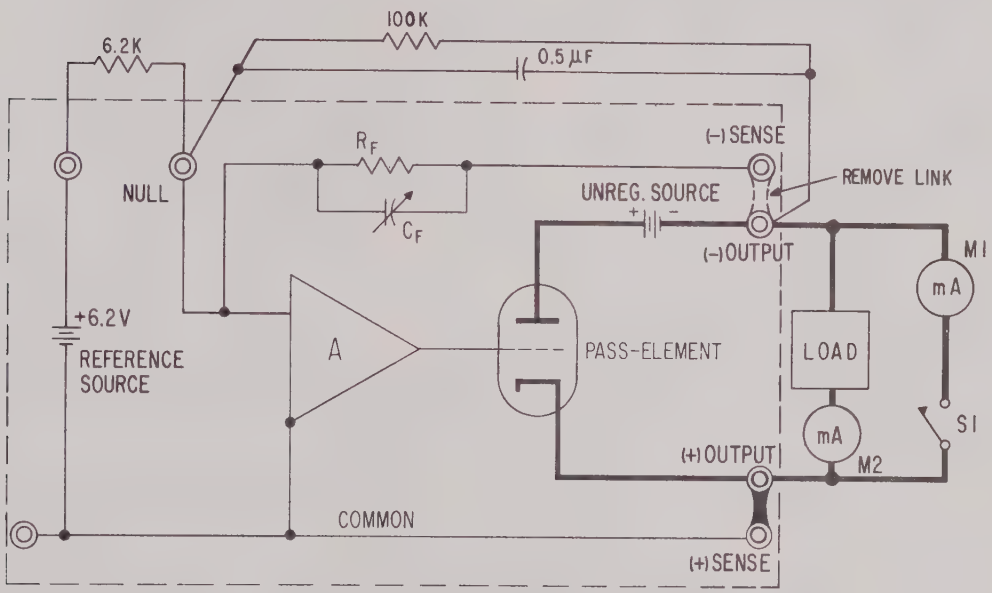


FIG. 3-14 SET–UP FOR CURRENT LIMIT ADJUSTMENT

3-37 PROCEDURE

a) Set up the OPS in the operational power supply connection as shown in FIG. 3-14. (The set-up is shown for 100 V DC output, but any other ratio of R_f/R_i producing different output voltages may be selected).
b) Connect milliammeters and S1 as shown.
c) Close S1 and turn unit "on". Read out the short circuit current and adjust the "CURRENT CONTROL" at the front panel for the desired amount.
d) Open S1 and observe load current on M2. The difference between the short cirucit current (I_{SC}) and the load current (I_O) may be minimized by turning the "CURRENT REGULATION COMPENSATOR" on the front panel.

3-38 **REMOTE ERROR SENSING.** The OPS is equipped with removable links between the signal carrying common bus and the positive output terminal and between the negative (–) output and the built-in feedback resistor (R_f). If the links are removed and the common as well as the internal feedback resistor is connected directly to the remote load, a low source resistance is provided and voltage drops due to long load wires can be compensated for (up to 0.5 V in each load wire). (Refer to FIG. 3-15.)

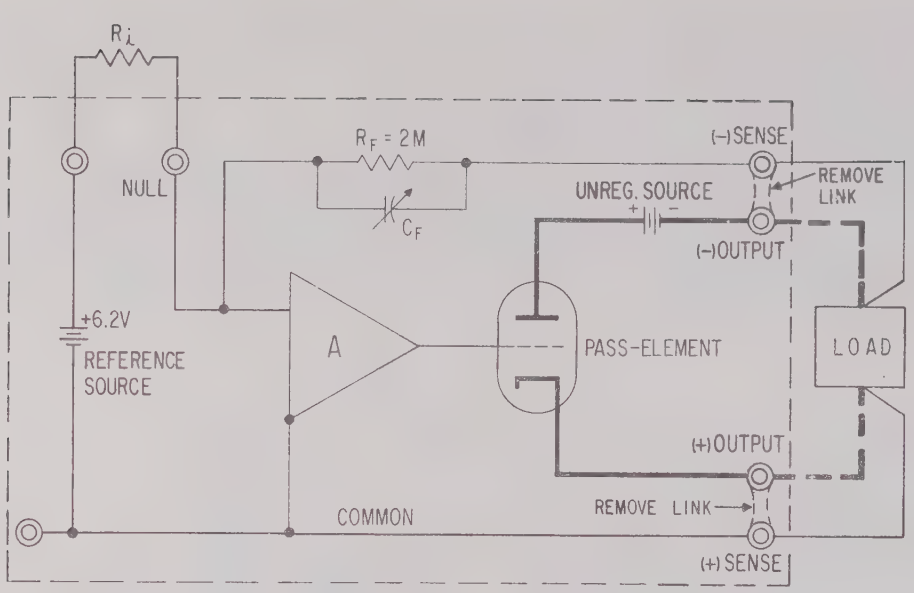


FIG. 3-15 REMOTE ERROR SENSING

3-39 THE OPS–HYBRID AS A CURRENT STABILIZER

3-40 The operating mode of the OPS is determined by the value of the feedback resistor (R_f), the setting of the (recessed) front panel CURRENT CONTROL (R_{CC}) and the load resistance (R_L). For any given set of values of the above, a sharp crossover exists, where the load resistance (R_L) is equal to the output voltage (E_O, determined by R_f) divided by the output current (I_O, determined by R_{CC}). If, for example, on a Model OPS–2000, the built-in feedback resistor is used (R_f = 2 M ohms) and the CURRENT CONTROL (R_{CC}) is set for the maximum rated output current (I_O = 10 mA), the OPS–2000 will cross over into the current stabilizer mode when:

$$R_L \leq \frac{E_O}{I_O} \text{ or } R_L \leq \frac{2000V}{10\ mA} < 200\ K\ ohms$$

As long as R_L remains smaller than 200 K ohms, the OPS–2000 will remain in the "Current Mode" of operation and provide stabilized output current into any load resistance from 0 to 200 K ohm. The output voltage will, of course, change proportional to the load resistance; for the above conditions, E_O will be 2000 volts with R_L = 200 K ohms and 0 volts with R_L = 0 ohms (short-circuit). The (idealized) crossover characteristic of the OPS–2000 is illustrated in FIG. 3-16 below.

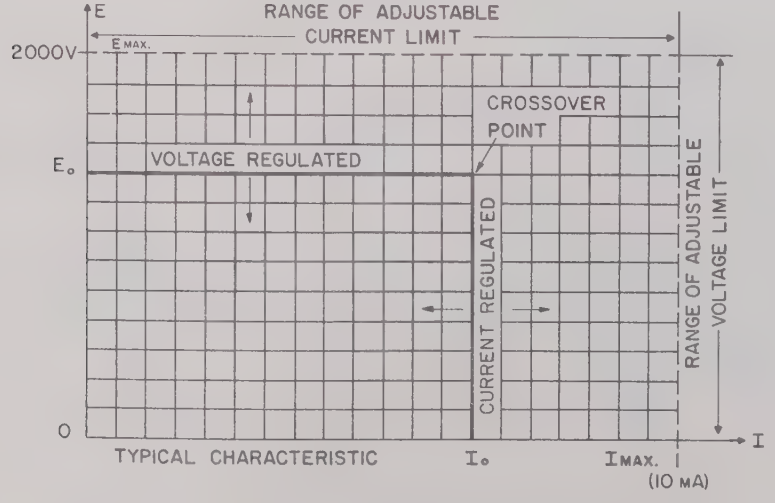
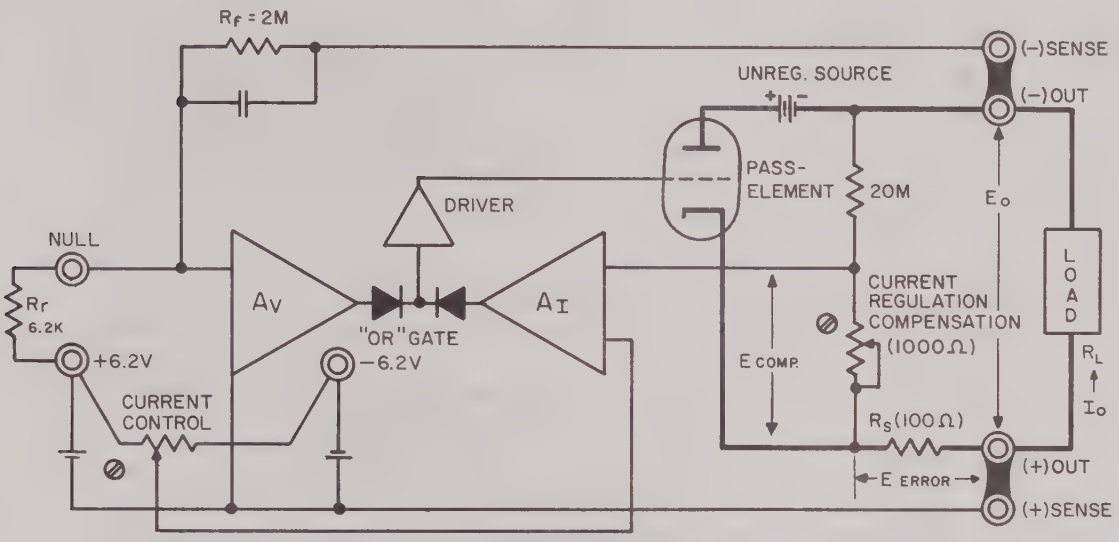


FIG. 3-16 AUTOMATIC VOLTAGE/CURRENT CROSSOVER (IDEALIZED).

3-41 In a cross-over device such as the OPS operating in the current mode, the feedback resistor (2 M ohm in the OPS–2000) appears effectively across the output, representing an internal "shunt load". The current flowing through the shunt load depends upon the value of the output (compliance) voltage and represents an error current since it is not flowing through the external load. A compensating circuit is provided in the OPS, which in effect produces a voltage drop opposing that produced by the error current flowing through the sensing resistor (R_S), thus effectively zeroing the effect of the error current, flowing through the feedback resistor. (Refer to FIG. 3-17).

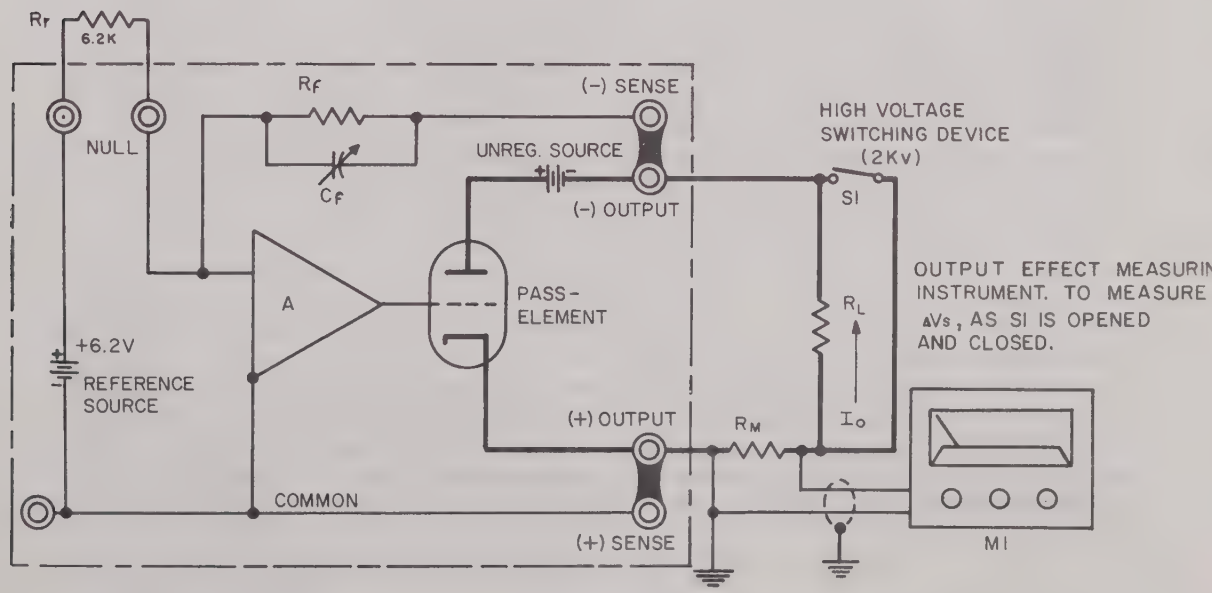


NOTE: The effect of the error current, E_O/R_f, is canceled if the Current Stabilizer Compensator is adjusted such that:

$E_{comp.} = E_{error} = 0.$

FIG. 3-17 OPS–HYBRID, SIMPLIFIED

3-42 The CURRENT STABILIZATION COMPENSATOR (recessed screw-driver adjustment at the front panel) of the OPS Hybrid models has been factory-adjusted for best current stabilization (lowest output effect) at 10% output current. The adjustment may be optimized for other load currents, using a test set-up as illustrated in FIG. 3-18 below.



NOTE: Adjust front panel "Current Stabilizer Compensation" for smallest ΔV.

FIG. 3-18 TEST SET-UP FOR COMPENSATION ADJUSTMENT AND OUTPUT EFFECT MEASUREMENTS IN THE CURRENT MODE.

3-43 For remote current control the OPS may be set-up with external sensing and control resistors. Since the voltage amplifier is used in this case to stabilize the output current across an external sensing element (R_S) the voltage limiting feature of a crossover type regulator is of course lost in this application. FIG. 3-19 below shows the necessary connection for remote control of the output current.

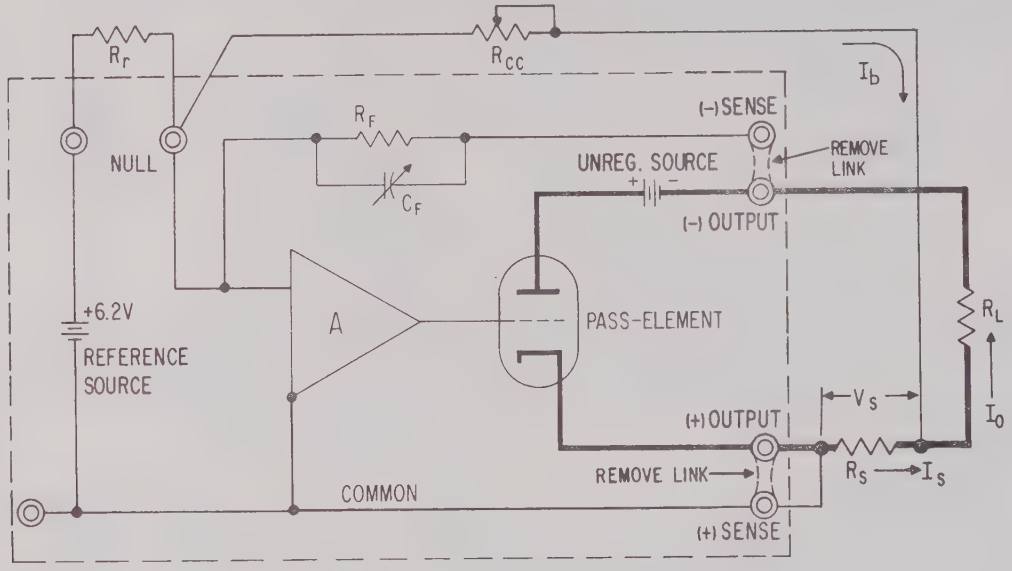


FIG. 3-19 REMOTE CURRENT CONTROL WITH EXTERNAL SENSING, OPS–HYBRID

3-44 Component Selection will be shown by means of an example. An OPS 2000 is to be connected as a current stabilizer with the output current adjustable from 1 mA to 10 mA. If 10 volts of sensing voltage (V_S) is chosen across R_S at I_O = 10 mA, the value of the sensing resistor is given by:

$$R_S = \frac{10\ V}{0.01\ A} = 1000 \text{ ohms}$$

A wirewound resistor, at least one watt, with low temperature coefficient should be chosen. The necessary control current, actually derived from the programming source, will here be taken from the internal reference source. If we chose 1 mA for the control current I_b, we need a 6.2 K ohm reference (R_r) in series with the built-in 6.2 V reference source E_r: $I_b = E_r/R_r$.

R_{CC}, the current control resistor, is now determined by making use of the balancing equation:

$$\frac{E_r}{R_r} = \frac{V_S}{R_{CC}}$$

Since we made $E_r/R_r = I_b = 1$ mA, $R_{CC} = \frac{V_S}{I_b} = \frac{10\ V}{1\ mA} = 10\ K\Omega$

Connecting the components as shown in FIG. 3-19 the output current can be controlled (by varying R_{CC}) in the range from 1 to 10 mA. The OPS in this configuration represents a constant current operational power supply. If the control current is derived from a variable input source, R_{CC} may be a fixed resistance. For the application discussed above, the compliance voltage change will be from 200 volts to 2000 volts, as the load changes from 200 K ohms to 2 M ohms. The full compliance voltage range of the OPS 2000 is zero to 2000 volts.

SECTION IV – CIRCUIT DESCRIPTION

4-1 GENERAL

4-2 This section contains a description of the major electrical circuits of the Kepco Hybrid Operational Power Supply. For the purpose of analysis the circuitry may be divided into several sections which are subsequently described below. (Refer to Main Schematic, FIG. 6-3)

a) AC INPUT CIRCUIT. AC line power is introduced through a three wire safety line cord with three prong plug. The third (green) wire of the cord is connected to the metal chassis of the instrument. The line cord is plugged into the AC input connector in the rear of the chassis (P201). The use of a grounded outlet in combination with the provided line cord will therefore automatically ground the metal chassis of the instrument.

If S1 is activated, the primary of T201 is energized. The two primary windings are either in parallel for 115 V AC nominal AC line voltage, or in series for 230 V AC operation. Simultaneously with T201, line power indicator DS101 will be energized. The slow blow type fuse (F201) protects the primary of T201 from excessive current.

b) MAIN DC SUPPLY. The main DC power is derived from a single winding on T201. A bridge rectifier circuit with CR301 through CR304 works into a capacitive input. The input capacitor (C201) is paralleled by the bleeder resistor R201. The main DC supply delivers the output power through the series regulator or pass-tube V301.

c) SERIES REGULATOR (PASS–) ELEMENT. The pass tube V301 is connected in series with the unregulated main DC supply and the output terminals. By changing its equivalent resistance, the voltage drop across it is made to change in such a way as to keep the output voltage constant. The grid signal necessary to affect this change is supplied by driver transistor Q6 which is the "output stage" of the DC amplifier.

d) DC AMPLIFIER. The DC amplifier consists of the complementary input pair Q2 – Q3, the differential current limiter stage Q4 – Q5, the "or" gate CR7 – CR8 and the driver Q6. A signal appearing at the null junction (Base of Q2) will be amplified by Q2 and Q3 and transfered to the gate diode CR7. Simultaneously, the voltage across the internal sensing resistor R27 is compared with the voltage at the CURRENT CONTROL potentiometer wiper by differential transistor-pair Q4 – Q5. If the two base voltages are in balance, no signal output will be transfered to gate diode CR8. In this case the amplified signal from the input stage takes precedence, CR7 will conduct the signal to the driver stage Q6 and from there to the grid of V301. If, due to a rise in output current the voltage drop across R27 increases, the current limiter stage is unbalanced, resulting in a signal at CR8. If this signal is more positive than the signal from the input amplifier, CR8 will conduct, transfer the signal to the driver which will be cut-off, leaving a large negative signal at the series regulator, thus limiting the output current sharply.

e) AMPLIFIER POWER SUPPLY. Derived from a centertapped winding on T201, this full wave rectified (CR311,CR312) and capacitor filtered (C305) supply delivers the DC voltages for the amplifier and the reference sources. The DC voltage from the rectifier is pre-regulated by the series regulator transistor Q1 and the zener diodes CR2 – CR13 which supply the operating voltages.

The reference diodes (CR4 – CR5) are similary derived from the amplifier power supply and terminated at the rear as well as the front panel binding posts.

f) AUXILIARY SUPPLIES

1) The Screen Supply is derived from a centertapped winding on T201. The full wave rectified (CR305,CR306) supply is capacitor filtered by C303 and the voltage is applied between cathode and screen of V301 via the dropping resistor R302.

2) The Return Supply is a full-wave rectified, capacitor filtered supply (CR307 through, CR310,C304) connected across the output of the main supply. In series with a 1 megohm resistor the supply acts as a low current source to provide the proper return for the leakage current when the vacuum tube is operating near the cut-off condition.

3) The 6.3 V Fillament Supply provides unregulated heater voltage for V301.

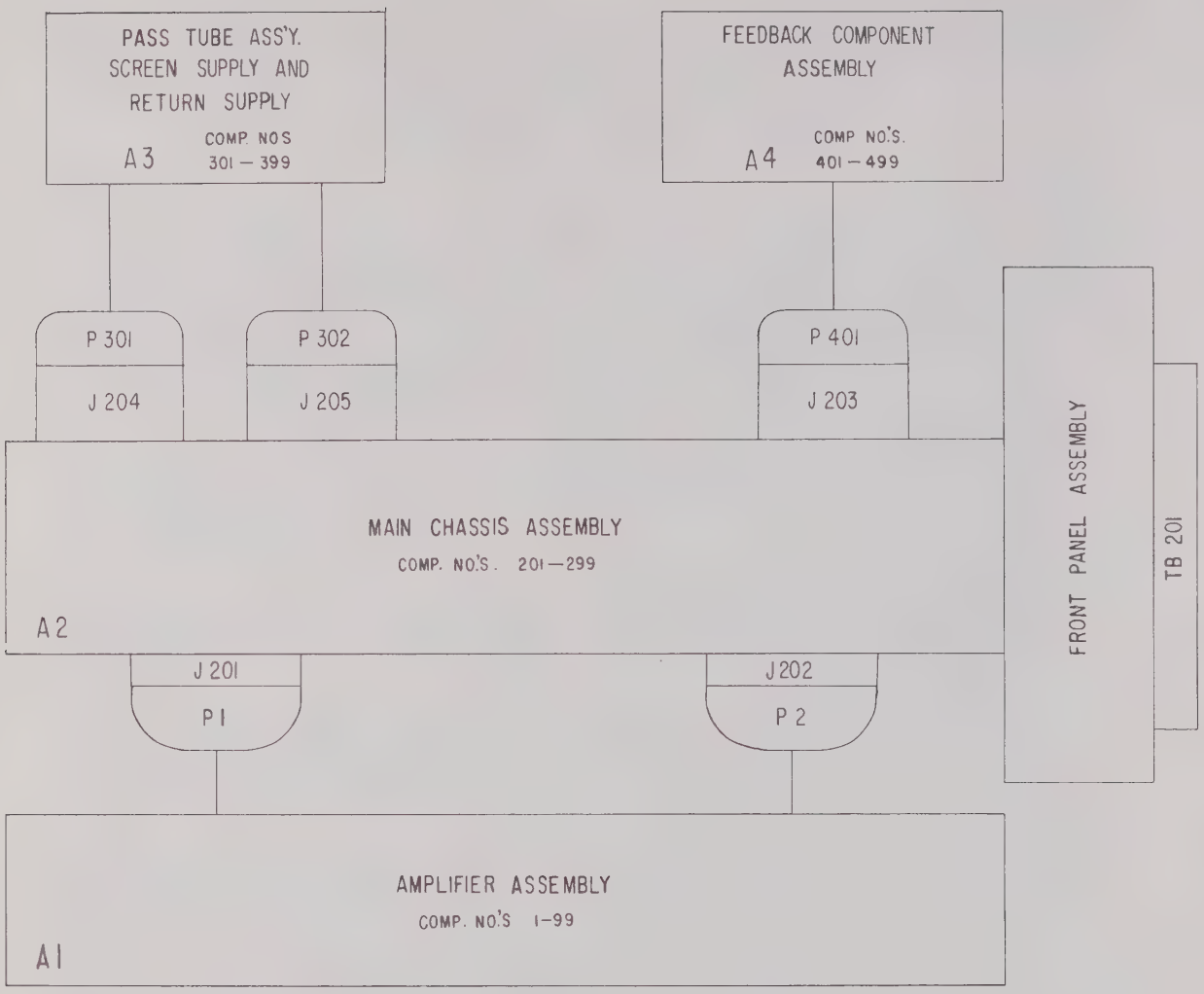


FIG. 4-1
CONNECTING DIAGRAM
AND TABLE

CONNECTORS

REFERENCE DESIGNATION AND NO. OF PINS.	MATING PLUG	PIN NO's NOT USED
J 202 (22)	P2	9,10,11,15,16,17.
J 203 (12)	P401	6 TO 10
J 204 (22)	P301	3 TO 11,14 TO 16,18 TO 21.
J 205 (22)	P302	5,7,9,10,11,12, 15,17,18,20,21.
J 201 (3)	P1	NONE
P 201 (3)	LINE CORD	NONE

SECTION V – MAINTENANCE

5-1 GENERAL

5-2 This section covers maintenance procedures and calibration of the Kepco OPS Hybrid Series as far as not covered previously in this manual. Conservative ratings of components and non-congested lay out should keep maintenance to a minimum. If trouble does develop however, the wrap around cover and the plug-in feature of the main component boards provide exceptional accessibility of the circuitry.

5-3 COVER REMOVAL

5-4 The wrap-around cover may be easily removed by loosening the two (2) black nickel screws on the front panel and the three (3) holding screws on each side of the unit.

5-5 CURRENT CONTROL, RANGE CALIBRATION

5-6 A recessed screw driver control is provided at the front panel which sets the range in which the output current limting can be controlled. Calibration is necessary only if the CURRENT CONTROL (R8) potentiometer, or components in the limiting circuitry have been replaced. The CURRENT CONTROL CAL (R6) is factory set to provide the specified range (See FIG. 3-13) on the CURRENT CONTROL. The CURRENT CONTROL CAL. (R6) is set by connecting the OPS as an operational power supply and providing for maximum rated current. With the CURRENT CONTROL (R8) fully clockwise, adjust R6 so that fully rated output current can be drawn from the unit. (See also par. 3-34)

5-7 TROUBLE SHOOTING

5-8 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the operational concept, experience with solid state circuitry, and appreciation of the problems encountered in closed loop systems. Repairs beyond simple part replacement and recalibration should therefore be handled only by competent personnel. "Trouble Shooting Charts", giving resistance and voltage ratings at various parts in the circuitry are of little value in feedback amplifiers and for this reason not encluded here. Presented instead are:

a) Extensive Operational Theory (Section III)
b) Parts Location Diagrams (FIG. 6-1, 6-2)
c) Main Schematic with Voltage Readings on all essential points. (FIG. 6-3)
d) Parts List (Section VI)
e) Circuit Description (Section IV)

It has been our experience that this material will provide the necessary information in the majority of all cases of equipment failure if handled by competent personnel. Kepco Field Engineering Offices and the Kepco Repair and Engineering Application Departments are always available for prompt service in difficult cases.

5-9 TEST MEASUREMENTS

5-10 GENERAL. Test measurements to verify the specifications of the operational power supply are often required as a part of incomming inspection, following repairs or as a part of a regular maintenance procedure. Adequate test facilities and equippment as well as great care in the performance of these measurements are of prime importance to insure valid results. Since many measurements on operational power supplies and amplifiers require specialized test equipment and rigidly controlled environment conditions, only the more readily verifiable ones are described here.

5-11 DC MEASUREMENTS. Variations of the offset voltage (ΔE_{io}) and offset current (ΔI_{io}) with AC input source changes over the specified range are an excellent indication of the DC performance of the operational power supply. These measurements may be readily duplicated by following the instructions and diagrams below:

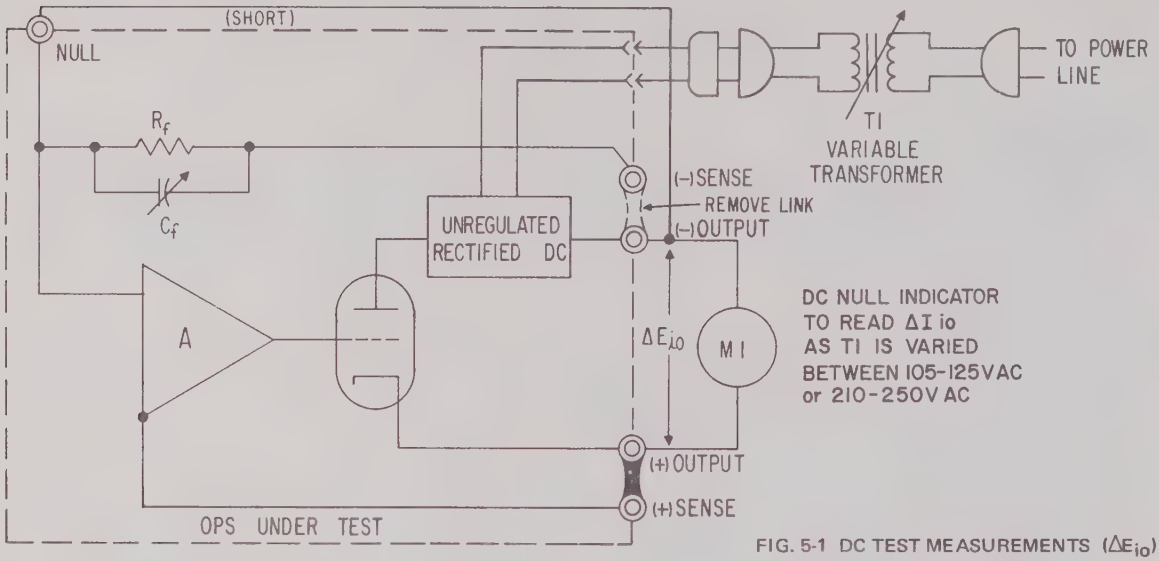


FIG. 5-1 DC TEST MEASUREMENTS (ΔE_{io})

a) Variations in Offset Voltage (ΔE_{io}). Measurements are made with the circuit shown in FIG. 5-1. Since the feedback terminals are shorted out ($R_f = 1$), and the input is disconnected, the operational gain is unity. Whatever offset voltage exists between null junction and common will be transferred directly to the output. Monitoring the output by means of a sensitive null detector while varying the AC input source (or temperature, or time if facilities permit) will allow measurement of ΔE_{io} at the output.

b) Variations in Offset Current (ΔI_{io}). Measurements are made with the circuit shown in FIG. 5-2. Since the offset current will have to flow through the feedback resistor, it produces an output voltage E_o which is equal to $I_{io}R_f$. If this output voltage is monitored while varying the AC input source (or temperature, or time if facilities permit) will yield an indication of ΔI_{io} when the output voltage is divided by the value of the feedback resistor.

$$(\Delta I_{io} = \frac{E_o}{R_f}).$$

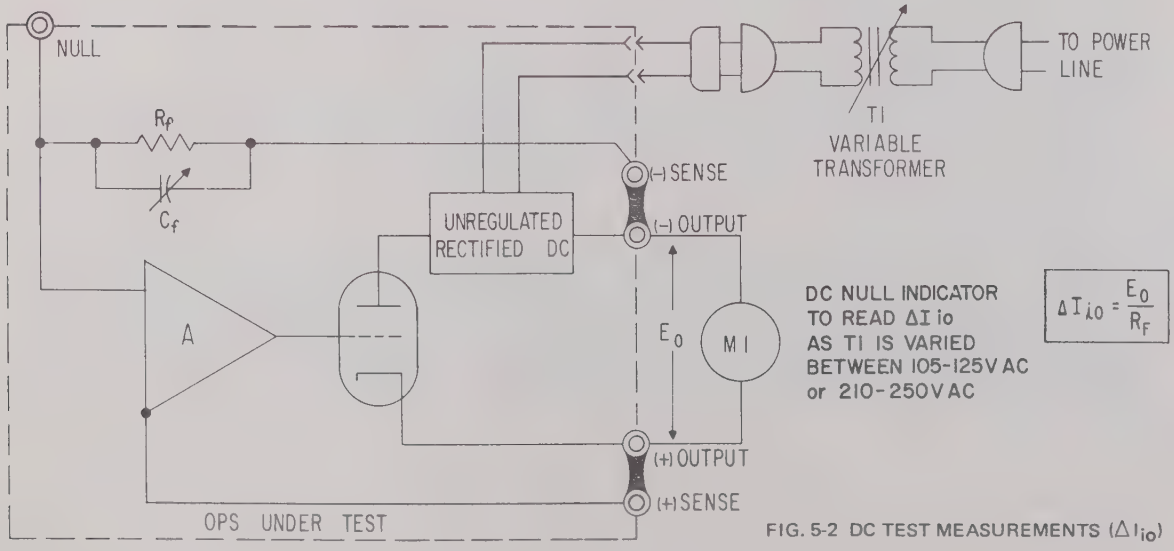
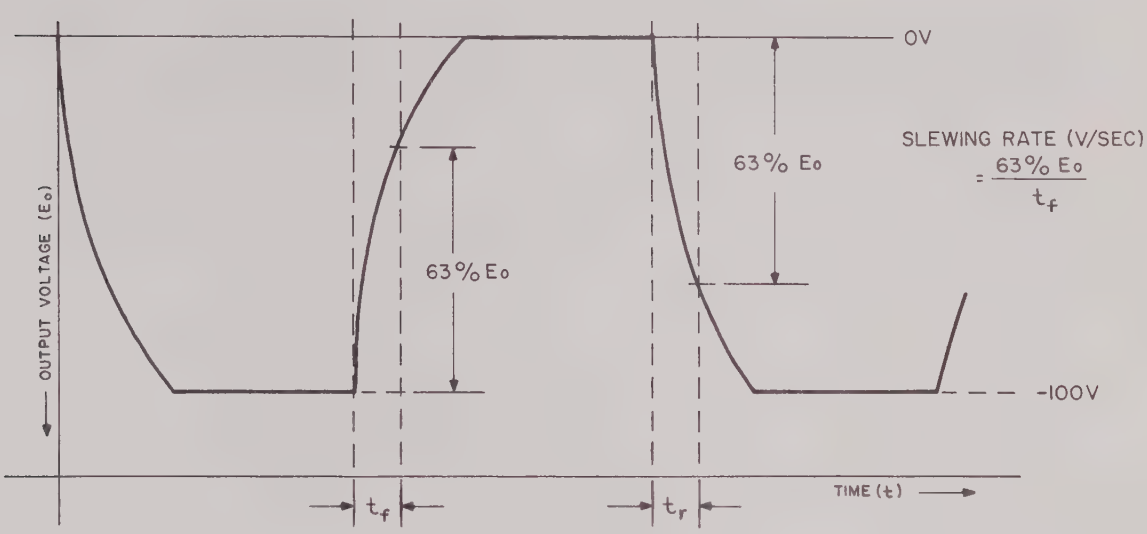
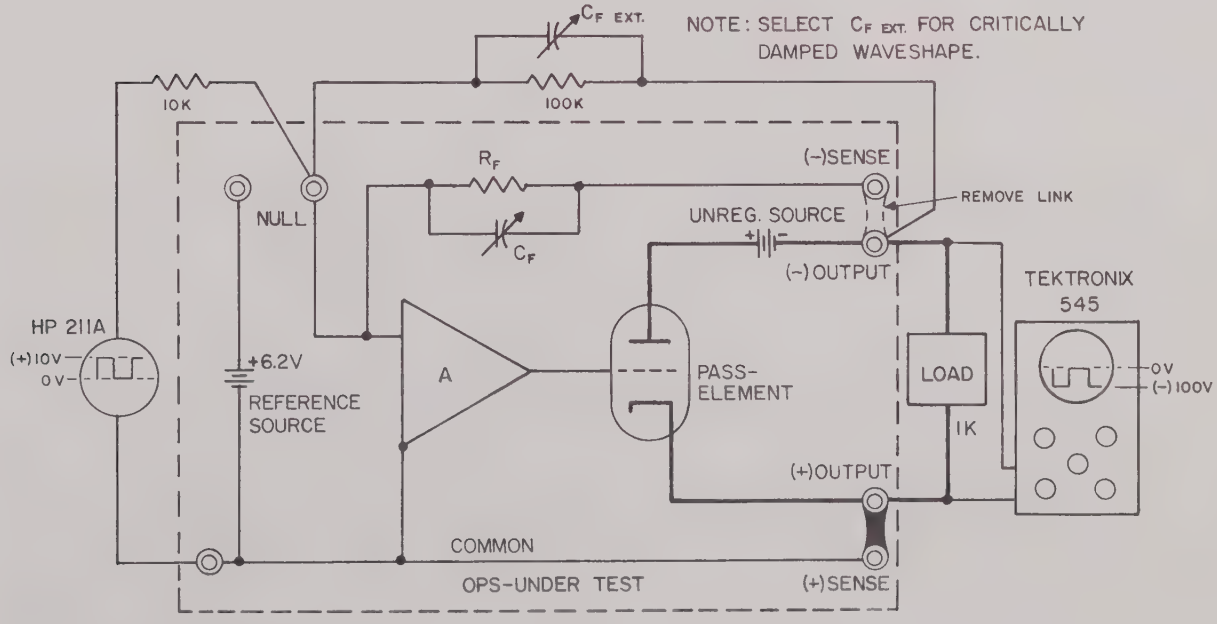


FIG. 5-2 DC TEST MEASUREMENTS (ΔI_{io})

5-12 AC MEASUREMENTS. The slewing rate or programming speed of the OPS may be verified by measuring the rise and fall time at the output when the instrument is programmed with a square wave in a low gain configuration. FIG. 5-3 shows the necessary test set-up. The specified slewing rate is calculated by measuring the fall time (worst case) of the output wave form and converting the results to "volt per second". And overshoot or other distortion encountered may be corrected by adjusting the AC stability as described in paragraph 3-21.



a) OUTPUT WAVE FORMS



b) INSTRUMENT SETUP

FIG. 5-3 AC TEST MEASUREMENTS (SLEWING RATES)

SECTION VI – ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131–38 Sanford Avenue
Flushing, N.Y. 11352

6-5 Specify the following information for each part:

a) Model and complete serial number of instrument.

b) Kepco part number.

c) Circuit reference designator.

d) Description.

6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

NOTE: KEPCO DOES NOT STOCK OR SELL COMPLETE POWER SUPPLY SUBASSEMBLIES AS DESCRIBED HERE AND ELSEWHERE IN THIS INSTRUCTION MANUAL. SOME OF THE REASONS ARE LISTED BELOW:

1) Replacement of a complete subassembly is a comparatively rare necessity.

2) Kepco's subassemblies are readily serviceable, since most of them are of the "plug-in" type.

3) All active components are socket mounted, making replacement extremely easy.

4) The nature of a closed-loop power supply system requires that subassembly replacement is followed by careful measurement of the total power supply performance. In addition, depending on the function of the subassembly, extensive alignment may be required to restore power supply performance to specified values.

IF REPAIRS INVOLVING SUBASSEMBLY REPLACEMENTS ARE REQUIRED, PLEASE CONSULT YOUR LOCAL KEPCO REPRESENTATIVE OR THE KEPCO SALES ENGINEERING DEPARTMENT IN FLUSHING, NEW YORK, N.Y.

AMPLIFIER ASSEMBLY (A1), MODEL OPS 500

Code 12-3169

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C1,2	2	Capacitor,Electrolytic,Pigtail 100 μF, 15 V	General Electric 76F02FL101	117-0523
C3	1	Capacitor,Mylar,Pigtail 0.5 μF, 200 V, 10%	Wesco Type 32MM	117-0575
C4	1	Capacitor,Mylar,Pigtail 0.1 μF, 200 V, 10%	Sprague 192P10402	117-0186
CR1,2,3	3	Zener Diode,Pigtail	International Rectifier 69-6603	121-0028
CR4,5	2	Zener Diode,Pigtail	IRC 1N821	121-0041
CR6,7,8, 9,10	5	Rectifier,Silicon,Pigtail	Semicon SM140/S	124-0028
CR11,12	2	Rectifier,Silicon,Pigtail	General Instrument KG100G	124-0163
CR13	1	Zener Diode	International Rectifier 1N1773	121-0012
Q1	1	Transistor,Silicon,NPN	RCA 2N3053	119-0059
Q2	1	Transistor,Silicon,PNP	Transitron 2N1132	119-0055
Q3,4,5	3	Transistor,Silicon,NPN	General Electric 2N336A	119-0056
Q6	1	Transistor,Silicon,PNP	Fairchild 119-0076	119-0076
R1	1	Resistor,Fixed,Precision,WW 510 ohm, 1 W, 1%	Tepro TS-1W	115-1466
R2	1	Resistor,Fixed,Precision,WW 6 8 K ohm, 3 W, 5%	Tepro TS-3W	115-1284
R3	1	Resistor,Fixed,Precision,M.F. 210 ohm, 1 W, 1%	IRC CES Type	115-1936
R4	1	Resistor,Fixed,Power,Axial 800 ohm, 3 W, 5%	Hardwick Hindle 9/16 GA-46-800	115-1215
R5	1	Resistor,Fixed,Precision,M.F. 392 ohm, 1 W, 1%	IRC CES Type	115-2060
R6	1	Resistor,Variable,Cermet 5 K ohm, 3/4 W, 20%	Helipot 78PR5K	115-1997
R7	1	Resistor,Fixed,Precision,M.F. 9090 ohm, 1 W, 1%	IRC CES Type	115-1998
R8	1	Resistor,Variable,Cermet 2 K ohm, 3/4 W, 20%	Helipot 78PR2K	115-2032

NOTE:
REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

AMPLIFIER ASSEMBLY (A1), MODEL OPS 500 **Code 12-3169**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
R9	1	Resistor,Fixed,Precision,M.F. 12.1 K ohm, 1 W, 1%	IRC CES Type	115-1817
R10	1	Resistor,Fixed,Molded 330 K ohm, 1/2 W, 10%	Allen Bradley EB3341	115-0778
R11,15	2	Resistor,Fixed,Precision,WW 1.3 K ohm, 1 W, 3%	Tepro TS-1W	115-1310
R12,13	2	Resistor,Fixed,Precision,M.F. 33.2 ohm, 1 W, 1%	IRC CES Type	115-1855
R14,17	2	Resistor,Variable,Cermet 50 ohm, 3/4 W, 20%	Helipot 78PR50	115-2055
R16	1	Resistor,Fixed,Precision,WW 560 ohm, 1 W, 1%	Tepro TS-1W	115-1696
R18	1	Resistor,Variable,Cermet 10 K ohm, 3/4 W, 20%	Helipot 78PR10K	115-2085
R19	1	Resistor,Fixed,Molded 100 K ohm, 1/2 W, 10%	Allen Bradley EB1041	115-0809
R20	1	Resistor,Fixed,Precision,M.F. 500 K ohm, 1 W, 1%	IRC CES Type	115-1801
R21	1	Resistor,Fixed,Precision,WW 25 K ohm, 3 W, 3%	Tepro TS-3C	115-1741
R22	1	Resistor,Fixed,Precision,WW 15 K ohm, 1 W, 3%	Tepro TS-1W	115-1414
R23,24	2	Resistor,Fixed,Precision,M.F. 11 K ohm, 1 W, 1%	IRC CES M-Coat	115-1804
R25	1	Resistor,Fixed,Precision,WW 5.7 K ohm, 1 W, 1%	Tepro TS-1W	115-1301
R26	1	Resistor,Fixed,Molded 1 K ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547
R27	1	Resistor,Fixed,Precision,WW 25 ohm, 3 W, 5%	Tepro TS-3C	115-0779
R28	1	Resistor,Variable,Cermet 500 ohm, 3/4 W, 20%	Beckman 78PR500	115-2063
R29	1	Resistor,Fixed,Precision,M.F. 909 ohm, 1 W, 1%	IRC CES Type	115-1976
R30	1	Resistor,Fixed,Composition,Film 20 Megohm, 1 W, 5%	IRC MVX-1	115-2147
R31	1	Resistor,Fixed,Molded 150 K ohm, 1/2 W, 5%	Allen Bradley EB1545	115-0243

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

MAIN CHASSIS ASSEMBLY (A2), MODEL OPS 500 **Code 12-3169**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
FRONT PANEL ASSEMBLY CONTAINS:				
DS101	1	Pilot Light Assembly	Industrial Devices 1040A75	152-0070
S101	1	Switch,SPST	Stackpole RS47FB	127-0230
C201	1	Capacitor,Paper,Can 6 μF, 1 K V	General Electric 23F1229	117-0740
F201	1	Fuse,Slo Blo 0.8 A	Bussman MDL-8/10	141-0027
R201	1	Resistor,Fixed,Molded 680 K ohm, 2 W, 10%	Allen Bradley HB6841	115-1281
T201	1	Transformer	Kepco Magnetics 100-1806	100-1806

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

AUXILIARY ASSEMBLY (A3), MODEL OPS 500 **Code 12-3169**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C301,302	2	Capacitor,Mylar,Pigtail 0.01 μF, 400 V, 20%	Sprague 192P10304	117-0361
C303	1	Capacitor,Electrolytic,Pigtail 60 μF, 175 V	General Electric 43F7790AA1	117-0466
C304	1	Capacitor,Mylar,Pigtail 0.25 μF, 1 K V, 20%	Good All 620S254010W	117-0066
C305	1	Capacitor,Electrolytic,Pigtail 80 μF, 120 V	General Electric 43F7515AA1	117-0427
C306	1	Capacitor,Ceramic,Disc. 680 pF, 6 K V, 20%	Centralab DD60-681	117-0721
CR301,302, 303,304	4	Rectifier,Silicon,Pigtail	General Instrument KG100F	124-0137
CR305,306, 311,312	4	Rectifier,Silicon,Pigtail	Semicon SM140/S	124-0028
CR307,308, 309,310	4	Rectifier,Silicon,Pigtail	General Instrument DG100M	124-0299
R301	1	Resistor,Fixed,Molded 150 K ohm, 1/2 W, 5%	Allen Bradley EB1545	115-0243
R302,303	2	Resistor,Fixed,Molded 1 K ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547
R305,306,307	3	Resistor,Fixed,Power,Axial 250 K ohm, 10 W, 3%	Tepro TS-10W	115-1254
R308	1	Resistor,Fixed,Molded 100 K ohm, 2 W, 10%	Allen Bradley HB1041	115-0197
V301	1	Vacuum Tube	General Electric 8068	126-0096

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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FEEDBACK COMPONENT ASSEMBLY (A4), MODEL OPS 500

Code 12-3169

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C401	1	Capacitor,Ceramic,Disc. 400 pF, 3 K V, 20%	Centralab DD30-401	117-0586
C402	1	Capacitor,Ceramic,Disc. 1000 pF, 3 K V, 20%	Centralab DD30-102	117-0583
C403	1	Capacitor,Ceramic,Disc. 2000 pF, 3 K V, 20%	Centralab DD30-202	117-0390
C404	1	Capacitor,Ceramic,Disc. 5000 pF, 2 K V, 20%	Sprague 20HKB-D5	117-0079
R401	1	Resistor,Fixed,Precision,WW 500 K ohm, 2 W, 1%	Marstan Electronics MAW-12	115-2410

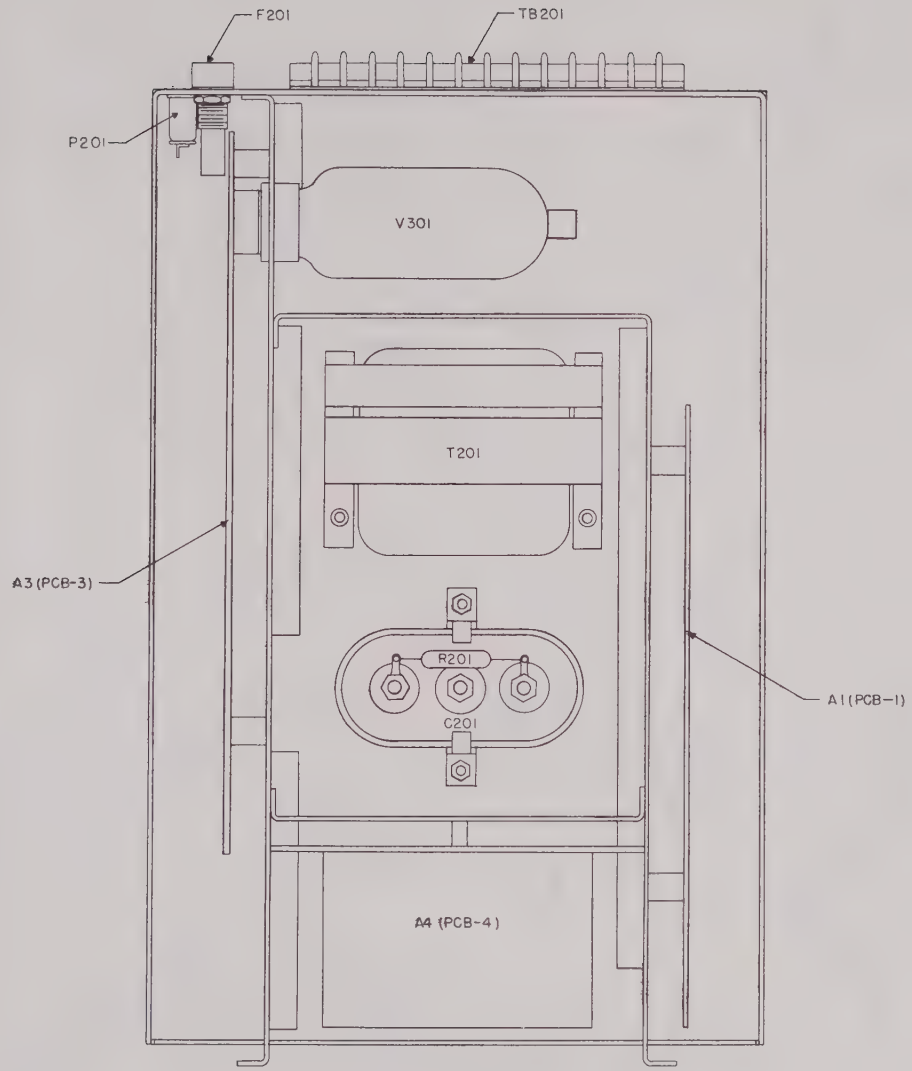
MISCELLANEOUS PARTS:

3	Binding Post, Red	151-0025
3	Binding Post, Black	151-0026
1	Binding Post, White	151-0029
1	Binding Post, Yellow	151-0055
1	Binding Post, Dark Blue	151-0027
1	Binding Post, Green	151-0048
1	Cabinet Cover	129-0092
4	Cabinet Foot	158-0001
1	Fuse Holder	150-0023
1	Handle	139-0208
1	Insulated Adjustment Tool	218-0004
1	Line Cord Assembly	118-0441
1	Transistor Heat Sink	136-0131
1	Tube-Retainer	179-0008
1	Vacuum Tube Anode Cap	178-0007

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



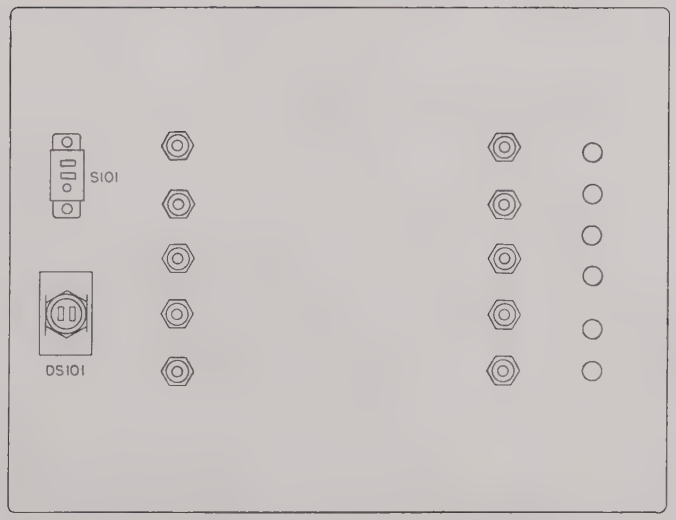
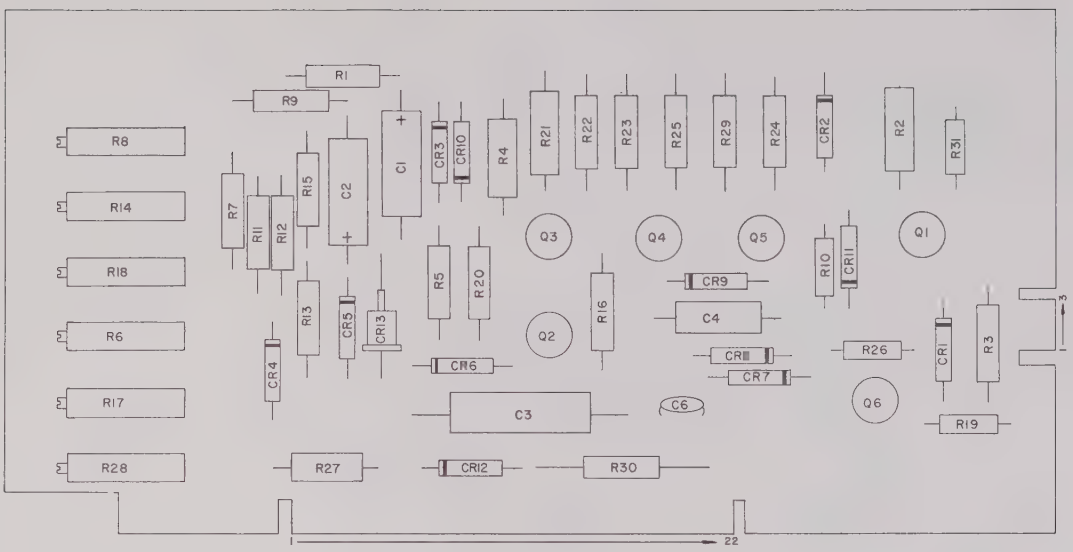
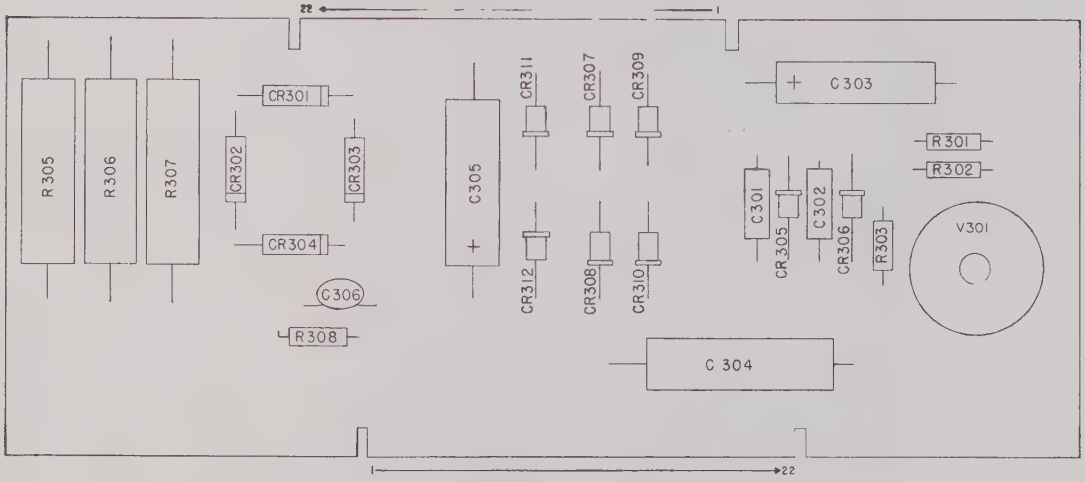


FIG. 6-1 COMPONENT LOCATION, MAIN CHASSIS.

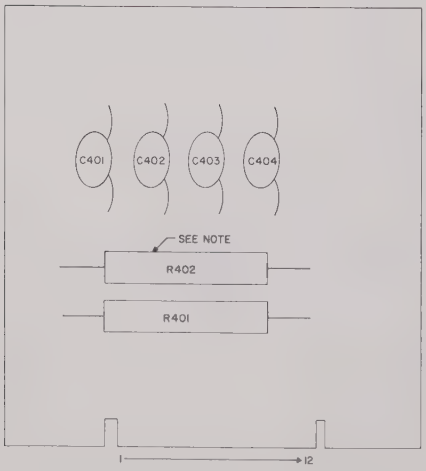


PCB–1 (A–1)

NOTE: C6 NOT USED IN OPS 2000.



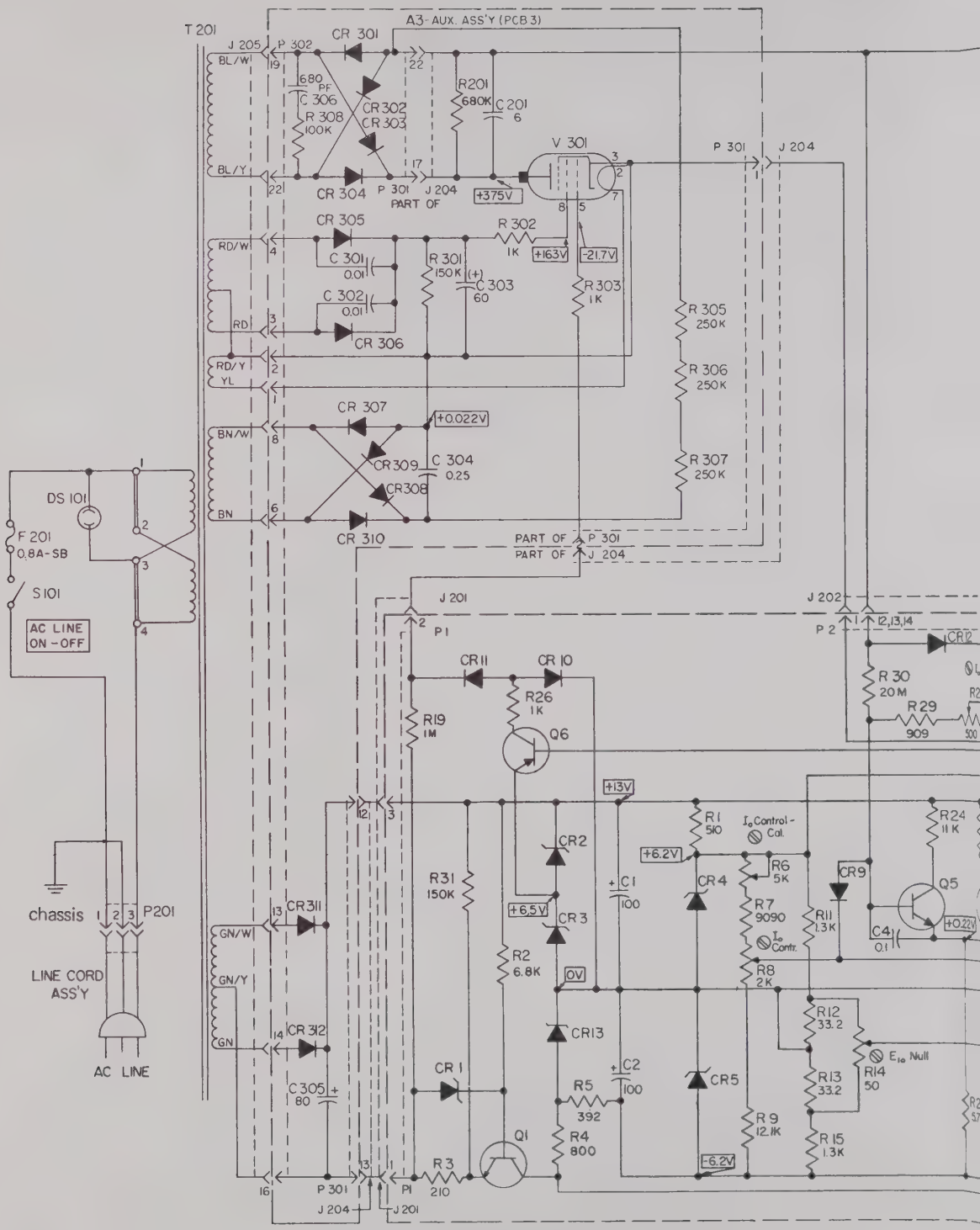
PCB–3 (A–3)



PCB–4 (A–4)

NOTE:
R402 NOT USED ON MODELS: OPS 500 AND OPS 1000

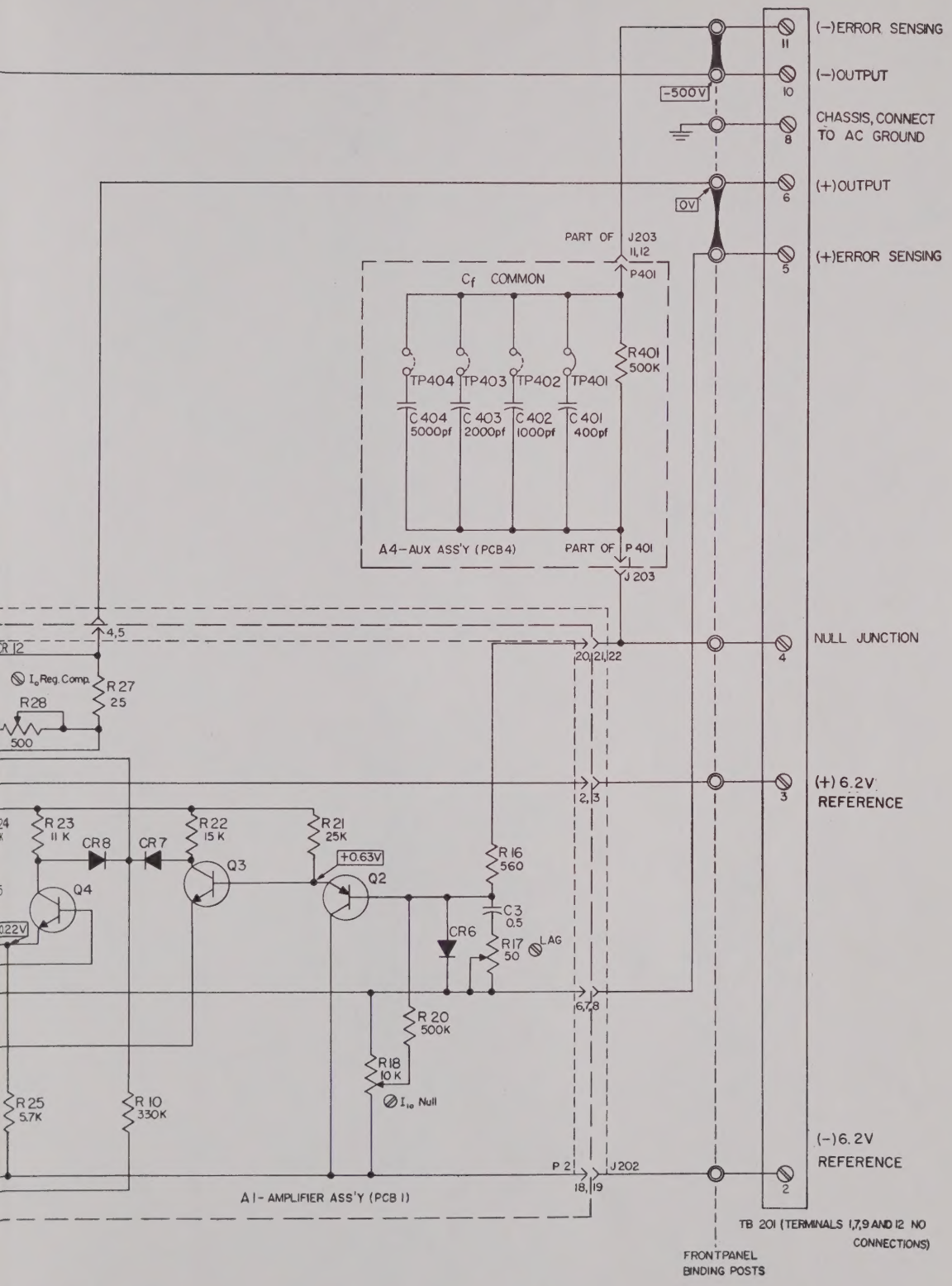
FIG. 6-2 COMPONENT LOCATION, PRINTED CIRCUIT BOARD.



NOTES:

1. ALL RESISTOR VALUES ARE IN OHMS, K = 1000
2. ALL CAPACITOR VALUES ARE IN MICRO FARADS, UNLESS
3. VOLTAGE READINGS ARE NOMINAL AND SUBJECT TO
   AC LINE INPUT AT 115V AC, OUTPUT AT 500 VDC IN RE
   TERMINAL, METER: 20K OHM PER VOLT, NO LOAD
4. TRANSFORMER CONNECTIONS SHOWN FOR 115 VAC OPE
   MANUAL FOR CONVERSION TO 230 VAC

kepco
Data subject to change without notice
PATENT NOTICE: Applicable Patent Nos.
® will be supplied on request.



ESS OTHERWISE INDICATED.
TO COMPONENT TOLERANCES
N RESPECT TO (+) OUTPUT

OPERATION SEE INSTR

FIG. 6-3 MAIN SCHEMATIC, MODEL OPS 500.

KEPCO.

INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the manual material as indicated:

Parts List and Schematic Diagram:

1. CHANGE:	R19	Resistor,Fixed,Molded	100 K ohm, 1/2 W, 10%	Kepco No. 115-0809 to:
	R19	Resistor,Fixed,Molded	1 megohm, 1/2 W, 5%	Kepco No. 115-0246.
2. CHANGE:	C3	Capacitor,Mylar,Pigtail	0.5 μF, 200V, 10%	Kepco No. 117-0575 to:
	C3	Capacitor,Mylar,Pigtail	1 μF, 200V, 10%	Kepco No. 117-0207.
3. ADD:	C6	Capacitor,Ceramic,Disc	0.002 μF, 3 KV, 20%	Kepco No. 117-0390.

NOTE: C6 has been added to PCB Assembly A1 and is connected in parallel with R16.

OPS 500/2-1870/r1	BMC
OPS 500/7-170/r2	C2420
OPS 500/5-771/r2	BMC

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